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The critical nitrogen percentage in the grain of maize single crosses and their parental lines, and the efficiency of nitrogen utilization by different single crosses

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The critical nitrogen percentage in the grain of maize single crosses and their parental lines, and the efficiency of nitrogen utilization by different single crosses

by

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GENERAL INTRODUCTION

The critical concentration of a nutrient element in a plant or plant part is the concentration at which maximum yield is attained with increasing amount of that nutrient made available for plant uptake. For many years, agricultural scientists have been interested in studying and utilizing the critical nutrient concentration in agronomic and horticultural crops as a measure of plant nutrient sufficiency and of the availability of soil and applied nutrients for maximum or economically optimum yields.

In the past three decades, fertilizer use in the United States, especially in the Corn Belt states, has increased dramatically. In Iowa, N fertilizer use increased from less than 13,000 metric tons in 1950 to more than 900,000 tons in 1979; and most of this fertilizer is applied to the maize crop. As a result of this increased use, and of improvements in maize hybrids and in soil and crop management practices, maize yields per hectare have increased more than 150% between 1950 and 1979 (30 to 80 q/ha). Recently, however, there has been a growing concern about the increasing cost of N fertilizer and the high energy use in N fertilizer production. Moreover, there has been concern about nitrate pollution of surface and underground waters from excessive or inefficient use of N fertilizers. Any plant or soil analysis method, therefore, that would provide more precise information on the N fertilizer needs of corn for optimum yield would be helpful from both the economic and environmental standpoints.

It is recognized that the critical concentration of a nutrient element in plants varies with different plant species and the plant part analyzed. It may also be affected by the environmental conditions under which the plants are grown. Less information is available regarding the extent to which different genotypes may vary in their critical percentages. Such information is needed for accurate use of plant composition in nutrient deficiency diagnosis.

Various investigators have found that the percentage of N in the grain of different corn hybrids may differ when compared at one level of soil N. Such comparisons may be of limited value if the level of soil N was insufficient to produce maximum yields or was so high that luxury consumption took place. In order to obtain comparable values for different hybrids, it is necessary to compare them all at maximum yields and thus obtain their critical N percentage (critical %N). This means that comprehensive experiments involving several rates of N under different conditions are needed.

Russell and Pierre (1980) recently suggested that the problem of determining the critical N percentage of the many hybrids available to farmers would be greatly expedited if the critical N percentage of the parental inbreds were known, for they and others have found a relatively high degree of correlation between the N percentage of hybrids and their parental inbreds even when grown at one level of N.

A knowledge of the critical N percentage of different maize genotypes is also essential in comparing their relative N yields and their efficiencies in N fertilizer use. It is well-known, for example, that the percentage N recovery by plants of the N applied in fertilizers is greatly influenced by the amount of N applied. The only valid comparison of hybrids, therefore, is on the basis of their maximum yields and critical %N.

The major objectives of this investigation were: (1) to determine the extent to which various maize hybrids differed in critical %N of the grain--the N content at maximum yield with respect to N; (2) to determine the constancy of these values in different seasons; (3) to determine if the critical %N in the grain of the parental inbreds can be used in predicting the critical %N in the grain of the single-cross progeny; and (4) to evaluate the efficiency of different single-cross hybrids in their use of applied N fertilizer.

An incidental objective was to examine the relationship between the critical %N and the associated P percentage in maize grain.

LITERATURE REVIEW

Soil and plant scientists have long been interested in studying the chemical composition of plants in relation to plant nutrition and to nutrient deficiencies in soils. More recently, they have been interested in studying the effects of differences in plant genotypes on plant composition and nutrient deficiencies. One of the most comprehensive reviews of this general subject has been that of Goodall and Gregory (1947). Less extensive general reviews have been made by Nelson (1956), Smith (1962), Bates (1971), Ulrich and Hills (1973), and others.

Critical Nutrient Concentration

Definition

Macy (1936) cited Pfeiffer and his coworkers as having proposed that a definite relationship exists between the percentage of a nutrient in a plant and its sufficiency for maximum yield. After reviewing the early literature, Macy (1936) outlined a theory in which curves relating yield and plant nutrient composition to nutrient supply were divided into three segments: (a) minimum percentage, (b) poverty adjustment, and (c) luxury consumption.

The minimum percentage region of these curves is characterized by a very large increase in yield without any or with very little change in the internal nutrient concentration as the level of that nutrient is increased. This would likely be experienced only when the nutrient concerned is very deficient. In the poverty adjustment region, both the yield and nutrient concentration increase as the nutrient supply increases. With further increases in nutrient supply, the yield remains constant while the nutrient concentration continues to increase; this is the luxury consumption region. The critical nutrient percentage was defined as the point of transition between the poverty adjustment and luxury consumption regions, or the concentration at the nutrient supply level required to maximize yield with respect to that nutrient.

Macy's (1936) concept of critical nutrient percentage has been generally accepted, and has been the basis for many investigations of plant nutrient sufficiency for crop production. Jones (1967) defined a critical nutrient percentage value as that concentration above which sufficiency occurs and below which deficiency occurs. Although agreeing in general with Macy's (1936) definition of critical nutrient percentage, some researchers have used some slight modifications for the purpose of economic interpretations (Ulrich, 1943, 1952; Bennett et al., 1953; Reichman et al., 1959; Fulton and Findlay, 1960; Ulrich and Hills, 1973). Fulton and Findlay (1960) referred to the critical nutrient percentage as the point at which yield increases are no longer of economic value. Bennett et al. (1953) and Reichman et al. (1959) defined critical %N at 95% of the maximum yield level, and Ulrich and Hills (1973), working with sugar beets, used 90% of maximum yield.

Ulrich (1943, 1952) pointed out that the critical nutrient concentration as determined experimentally was not a point but a narrow range of nutrient concentrations above which the plant is amply supplied with the nutrient and below which the plant is deficient. Dumenil (1961) indicated that the range in values may be wide depending upon how the critical nutrient concentration is defined and on the level of other factors that interact with the specified nutrient.

Determination

Since the critical nutrient concentration is defined in relation to maximum yield, determination of the critical percentage is dependent on first determining the maximum yield. Two methods of determining maximum yield were used by Pierre et al. (1977b): (a) regression analysis and (b) the graphical method. They described two different regression procedures, which were designated as the direct regression procedure and the two-step regression procedure. With both of the regression procedures and with the graphical method, the maximum yield is first determined and from it the associated nutrient percentage. In both procedures the nutrient percentage at maximum yield with respect to that nutrient is referred to as the critical percentage.

The direct procedure of regressing yields on the nutrient concentration was recommended by Goodall and Gregory (1947). This method has been used to calculate critical percentages by a number of investigators, among which are Bennett et al. (1953), Viets et al. (1954), Dumenil (1961), Swanson et al. (1970), Voss et al. (1970a, 1970b), and Powell and Webb (1972, 1974). Various other regression equations have been used with field data, such as (1) the Mitscherlich equation (Bennett et al., 1953; Swanson et al., 1970), (2) a quadratic polynomial function (Viets et al., 1954; Dumenil, 1961; Voss et al., 1970a, 1970b; Swanson et al., 1970; Powell and Webb, 1972, 1974; Pierre et al., 1977b; and others), and (3) a square root transformation of the quadratic function (Swanson et al., 1970). The quadratic regression of yield on nutrient percentage has been widely accepted and used because of its ease in determining the maximum yields and associated critical nutrient percentages. However, some of the limitations of the quadratic model have been pointed out by Putter et al. (1966) and by Baldock (1980).

The two-step regression procedure, as described by Pierre et al. (1977b), requires separate regression of yield and nutrient content on the quadratic function of the fertilizer rates. The maximum yield and the rate of nutrient required to obtain maximum yield were determined from the first regression equation. The critical nutrient percentage was then determined from the second regression equation by using the rate of nutrient required to maximize yields. Pierre et al. (1977b) observed that more rational fit of the observed yield and nutrient percentage data was obtained with the two-step procedure than with the direct procedure. Also, the nutrient rate required to maximize yields could be determined from the two-step procedure, but not from the direct procedure.

The maximum yield and associated critical nutrient percentage may also be determined by a graphical method such as that described by Pierre et al. (1977b). They considered the maximum yield to be the highest yield that was significantly higher than the yield from the next lower rate of the fertilizer nutrient. The nutrient concentration corresponding to this maximum yield was considered to be the critical percentage.

Critical N Percentages for Maize

Most investigations regarding the critical %N for maize as a measure of N sufficiency have used a specific leaf of the plant, sampled at a given stage of plant development. Tyner and Webb (1946) conducted one of the first investigations of the relationship between the N, P, and K composition of maize leaves and maximum grain yields resulting from additions of these nutrients. Tyner (1946) later suggested a critical %N of 2.9.

Only a few investigators have used the corn grain as a measure of N sufficiency. Pierre et al. (1977b) determined the critical %N values of maize grain from 6 N-rate experiments involving 13 site-years in Iowa, and calculated values from data reported in experiments from four other states and one province of Canada. Average critical %N values of 1.54%, 1.57%, and 1.68% were found for the Iowa, other states, and Canadian sites, respectively. Some of this variability was believed to be due to error and difficulties involved in determining the maximum yields. It was suggested, however, that some may have been due to the different hybrids used in different experiments; however, other growth factors were not eliminated as possible causes. Some data for corn grain have also been reported by Bennett et al. (1953) and by Fulton and Findlay (1960).

In addition to the use of leaves and grain as measures of N sufficiency, the total plant (grain plus stover) has also been used. Stanford (1973) found that maximum yields of grain and stover were obtained at N percentages of 1.20 to 1.30%.

Differences in N Percentage Among Maize Genotypes

A number of investigators have observed differences in the N concentration or crude protein content in the grain of different maize hybrids (Doty et al., 1946; Norden et al., 1952; Genter et al., 1956; Pollmer et al., 1978; Russell and Pierre, 1980; and others). However, practically all of these studies have involved a single level of soil and fertilizer N, since the main interest was in relative crude protein content of the grain rather than yield response to applied N. These single levels were assumed to be adequate for high yields, but, provided no assurance that all hybrids attained the same level of N sufficiency. Some of the higher yielding hybrids may not have attained maximum yields, while others may have had enough N for luxury consumption. Under such conditions, the critical %N of the grain of different hybrids are not strictly comparable. Thus, a comparison of genotypes should be done at maximum yield with respect to that element, or some given percentage of maximum yield. No investigations, however, have been conducted to determine how genotypes differ in their plant nutrient composition when compared at maximum yields with respect to that element.

Relationship Between the N Percentage in Maize Grain of Single Crosses and Their Parental Inbreds

Genter et al. (1957), Mann et al. (1978), and Russell and Pierre (1980) have indicated that there was a highly significant correlation between the N concentration in grain of maize parental inbreds and their single-cross progeny. Russell and Pierre (1980) measured the grain N content of approximately 50 single-cross hybrids and 15 inbred lines grown at two sites in Iowa in 1976 and found simple correlation coefficients of 0.84** and 0.65** between the N content of the hybrids and the mean of the two parents. They reported no evidence of dominance in the inheritance of N content in either experiment, and the r-values indicated that gene action was primarily additive for N content. These observations, however, were made at one level of N supply for the different inbreds and hybrids. Thus, it is impossible to obtain the true relationship since the genotypes may have differed either in the degree of N sufficiency or N excess. No investigations have been made of the relationship between the critical %N in the grain of maize single crosses and that in their parental inbreds.

If the grain of maize hybrids differ significantly in critical %N, it will be necessary to know this value for the many hybrids used in corn production before the critical %N of the hybrids can be used generally for N sufficiency diagnosis and for characterizing hybrids for their protein feeding value. Such determinations would normally require many comprehensive N-rate experiments. If, however, the critical %N of single crosses can be predicted from the critical %N of the parental inbreds, the work could be greatly expedited, as suggested by Russell and Pierre (1980).

Factors Affecting Critical N Percentage

It has been suggested by a number of investigators that the critical %N of maize may be influenced by several factors but there has been only a limited study of such factors. Tyner (1946) suggested a value of 2.90 %N as the critical concentration in the sixth leaf of maize at the bloom stage but observed that it varied with the time of leaf sampling and indicated that further experimentation was needed to determine the effect of different hybrids, locations, soil types, and seasons on the constancy of the critical %N values. Bennett et al. (1953), Dumenil (1961), Voss et al. (1970a) and others have verified the fact that these and other growth factors may significantly influence the critical nutrient percentage of plants or plant parts. It is presently recognized that interpretation of leaf analyses should include consideration of soil, management, and climatic factors. However, very little consideration has been given to the effect of genotypes on the critical %N of leaf samples.

Stanford (1973) reported that critical %N in total dry matter (grain plus stover) of maize was unaffected by variety, location, climate, or attainable yield level. Pierre et al. (1977a, 1977b) suggested several factors that might cause variations in critical %N in maize grain. They mentioned particularly hybrids, plant density, drought or moisture stress, and level of other nutrients as possible influencing factors. Recently, Miranda (1981) made a rather comprehensive study of several factors that might influence the critical %N in maize leaves and grain. He found that a moderate to severe moisture stress increased the critical %N in the grain and decreased it in leaves, and that increased P supply increased it in both grain and leaves.

Measures of N Utilization Efficiency

Performance trials have been conducted in most of the Corn Belt states in which maize hybrids have been compared for yielding ability as well as for some other agronomic traits (Ziegler and Campbell, 1980; Minor et al., 1980; Ross et al., 1980; and others). It is commonly assumed by maize producers that the most efficient hybrid is the one with the largest yield, even though other traits are considered. However, in these performance tests only one level of applied N is usually used, one that is believed to be adequate to produce high yields. It is desirable to know, however, how maize hybrids and inbreds may differ in their response to N fertilizer when compared at their respective maximum yield level.

Viets and Domingo (1948) and Dumenil (1952) referred to N efficiency as the amount of N required per unit of yield increase. Pierre et al. (1977a) found that the amount of N required per unit of yield increase, referred to as the N-requirement index, was affected by the initial relative yield, expressed as a percentage of the maximum yield. This is because the yield response curves are usually curvilinear. Therefore, they suggested that for most satisfactory comparisons among experiments or hybrids, the N requirement indexes should be made at the same relative yield with respect to the maximum yield. Obviously, N efficiency could also be studied and expressed in terms of the amount of yield increase per unit of N fertilizer applied (Welch, 1979; Capurro and Voss, 1981).

Allison (1966) pointed out that there are two commonly used methods of determining N recovery: (a) percent N recovered in vegetative tissue or grain (the N yield from fertilized plots minus the N yield from the unfertilized plots divided by the amount of N applied); and (b) actual percent recovery of added ^{15}N-labeled fertilizer. Nitrogen recovery data for maize grain by the N yield or unlabeled-N method have been reported in a number of investigations. As would be expected, the %N recovery is found to vary greatly with the amount of N applied in relation to the needs of the crop. At levels near maximum yield the %N recovery in the grain have, in general, ranged from about 30 to 45% (Ohlrogge et al., 1943; Viets and Domingo, 1948; Hunter and Yungen, 1955; Galvez et al., 1956; Pierre et al., 1971; Parr, 1973; Jolley and Pierre, 1977). Percent N recovery has not been used as a basis for studying N use efficiency by different maize genotypes. Jung et al. (1972), in a comparison of two maize hybrids, found that one recovered more of the indigenous N and more of the applied N at four of five rates than the other.

Gerloff (1976) used the term efficiency ratio as a means of expressing differences between tomato strains in N use efficiency. He defined these ratios as the mg of plant dry weight produced per mg element absorbed by a plant or plant part. There are no reports of maize genotypes having been compared for N use efficiency on the basis of efficiency ratios.

PART I. THE CRITICAL NITROGEN PERCENTAGE, MAXIMUM YIELD AND ASSOCIATED PHOSPHORUS PERCENTAGE OF COMMERCIAL AND PEDIGREE HYBRIDS

INTRODUCTION

A knowledge of the N or protein concentration in the grain of different maize hybrids is of interest from at least two standpoints: (1) the possibility of using the N percentage in the grain in plant nutrition studies and in N sufficiency diagnosis (Pierre et al., 1977b); and (2) the identification and comparison of different hybrids for their protein feeding value (Russell and Pierre, 1980).

It is generally recognized that both the N concentration and yield of plants are increased by additions of N to N-deficient soils. Macy (1936) developed the concept that there are three phases or zones describing this general relationship, namely: the zones of minimum percentage, poverty adjustment, and luxury consumption. Thus, as N is added to a soil very deficient in N, yields are at first increased, with little or no increase in N percentage (the zone of minimum concentration). As more N is supplied, both yield and N concentration are increased until a point or narrow zone is reached when yields no longer increase (the zone of poverty adjustment). Above this point (or narrow zone) the N concentration in the plant may continue to increase, giving a zone of luxury consumption. Macy (1936) designated the concentration of the nutrient at maximum yield as the critical nutrient concentration.

Many investigators have studied the critical N concentration (critical %N) in maize leaves taken at a given stage of plant development (Tyner, 1946; Viets et al., 1954; Dumenil, 1961; and others), and a few have determined the critical %N in maize grain (Bennett et al., 1953; Fulton and Findlay, 1960; Pierre et al., 1977b), but no studies have been reported on the critical %N of different maize hybrids.

It is well-known that the N percentages in the grain of different maize hybrids differ when compared at one rate of N or at the average of several rates (Norden et al., 1952; Zuber et al., 1954; Genter et al., 1957; Russell and Pierre, 1980). Since maize hybrids may differ in the amount of N required for maximum yields or are probably at different levels of N sufficiency, however, these values cannot be considered strictly comparable. They do, however, provide desirable proximate information.

It is also known that certain environmental and growth factors may affect the critical %N of maize grain. A review of this subject has been made by Bates (1971) and by Miranda (1981). Miranda's studies show that the critical %N in maize grain is lower at low P sufficiency. Miranda (1981) also found that the critical level of N is higher under severe moisture stress conditions. Further studies are needed on the extent to which these and other factors may influence the critical %N in maize grain. Critical %N will be considered in this investigation as the N concentration in the grain of maize that is at maximum yield with respect to N.

The general objectives of this study were:

1. To determine the extent to which various maize hybrids differ in critical %N in the grain.
2. To determine the constancy of the critical %N in maize grain for different hybrids in different site-years.

3. To determine the relationship in different site-years between the critical %N and the associated P percentages in maize grain.

PLANS AND PROCEDURES

The main part of this study involves data from two field experiments conducted in 1976 and 1977. A portion of related data from two additional experiments conducted in 1978 will be presented in this section with the remainder of the results from these experiments being discussed in Part II.

The 1976 experiment and one of the 1978 experiments were located on separate sites at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa. These sites will be referred to as A-76 and A-78 in the presentation of results. The 1977 and the other 1978 experiment were located on the same site at the Clarion-Webster Research Center near Kanawha, Iowa (CW-77 and CW-78).

The soil description, the initial soil-test levels, and the moisture-stress index for corn (Shaw, 1974) for each of the experiments are shown in Table 1.

Field Plot Design

All four experiments involved randomized complete block, split-plot designs in which N treatments were the main experimental units and maize hybrids were the subunits. Five replications were included in each experiment. The main plots were 6 meters wide by 23 meters long and the subunits consisted of a single 6-meter row of each hybrid in a 76 centimeter row spacing. Several border rows were planted around the outside of the experimental area.

The hybrids used in the experiments are listed in Table 2. The

Table 1. Soil chemical properties and weighted moisture-stress indexes for corn

Site-year	Soil name	Test levels for plow layer[a]			Moisture-stress index[b]
		pH	P (pp2m)	K (pp2m)	
A-76	Nicollet-Webster Complex (Aquic Hapludoll - Typic Haplaquoll)	6.2	31 (low-medium)	140 (low-medium)	25.3
CW-77	Webster silty-clay loam (Typic Haplaquoll)	6.8	92 (very high)	151 (medium)	14.9
A-78	Nicollet loam (Aquic Hapludoll)	6.6	36 (medium)	167 (medium)	1.1
CW-78[c]	Webster silty-clay loam (Typic Haplaquoll)	6.8	92 (very high)	151 (medium)	1.2

[a]Soil tests were run by the Soil Testing Laboratory, Agronomy Department, Iowa State University, Ames, Iowa.

[b]Computed as described by Shaw (1974).

[c]Same site as used in 1977.

Table 2. Maize hybrids used in the various experiments

A-76	CW-77	A-78	CW-78
A631 x A239	B14A x B75	B14A x B75	B14A x B75
A632 x Oh551	B14A x B76	B14A x B76	B14A x B76
B14A x B77	B14A x B77	B14A x B77	B14A x B77
B37 x B70	B14A x A619	B14A x A619	B14A x A619
B70 x B14A	B14A x Va26	B14A x Va26	B14A x Va26
B70 x B73	B14A x N7A	B14A x N7A	B14A x N7A
B73 x A619			
B75 x A632	Mo17 X B75	Mo17 x B75	Mo17 x B75
B75 x B37	Mo17 x B76	Mo17 x B76	Mo17 x B76
B77 x B37	Mo17 x B77	Mo17 x B77	Mo17 x B77
N7A x Mo17	Mo17 x A619	Mo17 x A619	Mo17 x A619
Oh545 x A632	Mo17 x Va26	Mo17 x Va26	Mo17 x Va26
	Mo17 x N7A	Mo17 x N7A	Mo17 x N7A
Ames Best SX37	B73 x B75	B73 x B75	B73 x B75
DeKalb XL43	B73 x B76	B73 x B76	B73 x B76
DeKalb X164	B73 x B77	B73 x B77	B73 x B77
DeKalb XL75	B73 x A619	B73 a A619	B73 x A619
Funks G4321A	B73 x Va26	B73 x Va26	B73 x Va26
Iowa State M116A	B73 x N7A	B73 x N7A	B73 x N7A
NK PX50A			
NK PX74	B14A x Mo17	B14A x Mo17	B14A x Mo17
Pioneer 3780	B14A x B73	B14A x B73	B14A x B73
Trojan TXS94	Mo17 x B73	Mo17 x B73	Mo17 x B73
Trojan TXS99			
Trojan TXS108A	A631 x A239		
Trojan TXS113	A632 x Oh551		
Trojan TXS119	B37 x B70		
	B70 x B14A		
	B70 x B73		
	B75 x A632		
	B75 x B37		
	B77 x B37		
	Oh545 x A632		

A-76 experiment included 14 commercial hybrids widely grown in Iowa and 12 high-yielding single crosses of known pedigree, providing for a comparison of the critical N percentages in a wide range of genetic material. The CW-77 experiment involved 30 pedigree single crosses, including the 12 which were used in the A-76 study. Both of the 1978 experiments included 21 pedigree single crosses, all of which were also in the CW-77 experiment. Consequently, the effect of site and seasonal differences could be evaluated for the 12 hybrids common to the A-76 and CW-77 sites and the 21 hybrids included in the CW-77, A-78, and CW-78 experiments.

Cultural Practices, Harvesting, and Processing

The preceding crop was oats on the A-76 site, soybeans on the CW-77 and A-78 sites, and corn on the CW-78 site. Sufficient P and K fertilizers were applied in the fall before plowing to insure an adequacy of these elements. In the following spring, before planting, the soils were tilled with a disk and/or field cultivator. Granular urea (46-0-0) was used as the N fertilizer source. The rates of N were 0, 67, 134, 201, and 268 kg/ha in the A-76 experiment and 0, 56, 112, 168, and 224 kg/ha in the other experiments. The urea was broadcast by hand immediately after planting, and the plots were harrowed very lightly to incorporate the fertilizer. Satisfactory weed control was accomplished with the use of recommended herbicides and some hand hoeing.

The planting was done by hand, dropping two seeds into each hill spaced about 25 centimeters apart in the row. After the plants were 25-30 centimeters tall, the stand was thinned to one plant per hill, or about 51,670 plants per hectare. The grain from individual plots was harvested by hand. Each sample was shelled, weighed, and subsampled to provide materials for moisture determination and chemical analyses. The moisture samples were dried at least 48 hours in a forced-air oven at 60 degrees C. Grain moisture was calculated and used to compute yields in quintals per hectare, adjusted to 15.5 percent moisture. The chemical samples were ground in a small hammer mill using a 40-mesh sieve. Broken kernels and kernels without tips were removed before grinding. The individually ground samples were mixed well and placed in a small glass bottle for storage until the time of chemical analysis.

Chemical Analyses

The ground samples were again dried in a small laboratory oven at 60 degrees C for at least 24 hours before analysis. A 0.25 g. sample was weighed, and digested in concentrated sulfuric acid with a salt/catalyst mixture (Nelson and Sommers, 1973). Digestion was done in tubes, placed in an electrically-heated aluminum digester block. Total N was determined from an aliquot of the diluted digest using a steam distillation process (Bremner and Keeney, 1965). Total P was determined on an aliquot of the diluted digest with a Klett Summerson photoelectric colorimeter, using the vanado-molybdate yellow color development method (Jackson, 1964). Both the N and P percentages of the grain were expressed on the oven-dry basis in percent of the dry matter. Duplicate analyses were made on each grain sample.

Statistical Analyses and Mathematical Computations

The grain yields and N and P data were analyzed, using the computer procedures available in the Statistical Analysis System (SAS Institute, Inc., 1979). A separate analysis of variance was performed on the yields and on the N and P percentages for each site-year.

The generalized regression models used in this study were:

$$\hat{Y} = b_0 + b_1N + b_{11}N^2 \tag{1}$$

$$\hat{n} = c_0 + c_1N + c_{11}N^2 \tag{2}$$

$$\hat{p} = d_0 + d_1N + d_{11}N^2 \tag{3}$$

where $\hat{Y}$, $\hat{n}$, and $\hat{p}$ are the predicted grain yields, N percentages, and P percentages, respectively; N is the rate of fertilizer; and the b values, c values, and d values are the regression coefficients of the respective regression models. In order to compute maximum grain yields and the N and P percentages associated with maximum yields, the rate of N fertilizer required to maximize yields was determined. To get this value, the first derivative of equation 1 was taken, set equal to zero, and solved for N as follows:

$$\frac{dY}{dN} = b_1 + 2b_{11}N = 0 \tag{4}$$

and

$$\hat{N} = -\frac{b_1}{2b_{11}} \tag{5}$$

where $\hat{N}$ is the predicted rate of N fertilizer required to maximize grain yields. By substituting $\hat{N}$ for N in equations 1, 2, and 3, the maximum yield, the critical N percentage (N percentage associated with maximum yield with respect to N), and the P percentage associated with maximum yield, respectively, were computed. The regression models shown in equations 1, 2, and 3 were used in separate computations for each hybrid in each experiment. This procedure of determining the predicted maximum grain yields, critical N percentages, and P percentages associated with maximum yields will be referred to as the "two-step regression method".

When $\hat{N}$ exceeded the highest rate of N fertilizer used in the experiment by more than one increment, a slight modification of the graphical method used by Pierre et al. (1977b) was employed to determine the maximum yield level and the associated percentages of N and P. A comparison of critical N percentages determined by the two-step regression and the graphical methods was made using correlation analyses. It was found that where both methods could be used on the same hybrids, a correlation coefficient of 0.95 was obtained, indicating very good agreement between the two methods. Thus, it was concluded that the graphical method would give acceptable critical N percentages in those few cases where N exceeded the limit mentioned above.

The maximum yield determined by the graphical method was considered to be the highest yield, provided it was significantly higher than the yield produced by either of the next two lower N rates. When the highest yield was not significantly higher than the yield at either of the next two lower N rates, the average of the highest yield and the yield from the next lower N rate was considered to be the maximum yield.

The N percentage in the grain associated with the maximum yield with respect to N will be referred to as the critical %N. The P percentage in the grain associated with the maximum yield will be referred to as the associated P percentage. Optimum protein will refer to the percent protein in the grain at maximum yield and will be computed by multiplying the critical %N times 6.25.

Analyses of variance were computed for the predicted parameters (a) by assuming a randomized complete block design in which the site-years were considered as replications, and (b) by assuming the variance for each site-year was the same. The relationships between maximum grain yields, critical N percentages, and associated P percentages for the hybrids in the two experiments were examined by correlation analyses.

RESULTS AND DISCUSSION

The data in Tables 1 and 3 show that a late-season deficit of rainfall caused moderate moisture stress in the A-76 experiment. However, an above average supply of subsoil moisture at the beginning of the growing season helped to compensate for the deficit of rainfall and yields were relatively high, averaging approximately 80 q/ha for the higher N treatments. Below normal rainfall during the early part of the season caused slight moisture stress in the CW-77 experiment, but favorable conditions during the latter part of the season resulted in maximum yields of about 105 q/ha. No moisture stress was observed in either of the 1978 experiments and yields of approximately 100 q/ha were attained.

Influence of N on Yield and N and P Concentration

The observed grain yields, N percentages, and P percentages (except for A-78 and CW-78) for the hybrids included in the various experiments are shown in Appendix Tables A1 through A10. Except for the CW-78 experiment, average yield responses were in the range of 25 to 30 q/ha. Since the same site was used for the CW-78 and CW-77 experiments and the control plots had not received any N either year, the control yields were very low in 1978 and a response of approximately 60 q/ha was obtained.

The mean squares from the analyses of variance of the observed grain yields, %N, and %P values available for each experiment are shown in Tables 4, 5, and 6. A highly significant quadratic response in grain yield to applied N was observed in all of the experiments. The differences in the observed yields among hybrids were highly significant in

Table 3. Actual precipitation and temperature and departure from normals for the growing season for each experimental site-year

Month	Site-year							
	A-76		CW-77		A-78		CW-78	
	Act.	Dep.	Act.	Dep.	Act.	Dep.	Act.	Dep.
	Precipitation (cm.)							
May	3.0	-1.5	1.6	-2.7	3.0	-1.5	2.7	-1.7
June	5.7	0.0	2.9	-2.3	5.4	-0.3	3.4	-1.8
July	1.1	-2.3	3.1	-1.0	6.8	3.4	4.6	0.5
August	0.3	-3.4	5.3	2.1	3.9	0.3	2.8	0.4
September	0.3	-2.9	3.3	0.1	5.6	2.3	4.9	1.7
October	0.9	-1.3	2.9	1.0	0.8	-1.4	1.1	-0.7
	Temperature (°C)							
May	59.0	-1.5	70.2	11.0	60.9	0.4	61.1	1.9
June	69.2	-0.3	73.6	4.8	70.6	1.1	69.0	0.2
July	74.7	1.1	77.1	4.3	73.1	-0.5	71.8	-1.0
August	71.4	-0.6	68.3	-2.8	71.5	-0.5	72.1	1.0
September	64.0	0.9	64.4	2.7	69.0	5.9	--	--
October	46.9	-6.6	--	--	50.7	-2.8	49.8	-2.2

Table 4. Analyses of variance for observed grain yields, %N, and %P for the 26 maize hybrids used in the A-76 experiment

Source	d.f.		Mean squares		
			Yields	%N[a]	%P[a]
Replications (R)	4		982.43	7.17	4.82**
Nitrogen (N)	4		14348.10**	401.68**	1.56
N_{ℓ} (linear)		1	31969.82**	1558.19**	0.52
N_q (quadratic)		1	21052.01**	34.88*	3.62*
N_d (deviation)		2	2185.28*	6.84	1.04
Error a	16		443.40	6.55	0.63
Hybrids (H)	25		1324.14**	18.39**	0.94**
H x N	100		118.70**	0.68**	0.03**
H x N_{ℓ}		25	208.44**	1.24**	0.07**
H x N_q		25	94.79	0.63+	0.02
H x N_d		50	268.05**	1.35**	0.42**
Error b	500		69.97	0.42	0.02
Total	649				
C.V. %			11.10	4.50	6.09

[a]Values were multiplied by 10^2.

+,*,**Represent statistical significance at the 10, 5, and 1 percent level of probability, respectively.

Table 5. Analyses of variance for observed grain yields, %N, and %P for the 30 maize single crosses used in the CW-77 experiment

Source	d.f.		Mean squares		
			Yield	%N[a]	%P[a]
Replications (R)	4		1854.77*	4.43	0.37
Nitrogen (N)	4		21127.48**	425.34**	0.03
N_{ℓ} (linear)		1	56063.19**	1536.22**	0.00
N_q (quadratic)		1	26781.37**	162.69**	0.03
N_d (deviation)		2	832.68	1.22	0.07
Error a	16		446.61	4.16	0.14
Hybrids (H)	29		2304.34**	25.40**	1.28**
H x N	116		139.00*	0.88**	0.03**
H x N_{ℓ}		29	233.25**	2.09**	0.05**
H x N_q		29	134.79	0.75**	0.03**
H x N_d		58	340.72**	1.19**	0.96**
Error b	580		106.08	0.30	0.01
Total	749				
C.V. %			10.42	4.02	3.53

[a]Values were multiplied by 10^2.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

Table 6. Analyses of variance for observed grain yields and %N for the 21 maize single crosses used in the A-78 and CW-78 experiments

Source	d.f.		Mean squares			
			A-78		CW-78	
			Yield	%N[a]	Yield	%N[a]
Replication (R)	4		542.68	10.57**	1128.63	13.70**
Nitrogen (N)	4		15935.06**	275.75**	72466.26**	609.55**
N_ℓ (linear)		1	54000.85**	1027.03**	236150.41**	2334.53**
N_q (quadratic)		1	8969.17**	75.05**	51683.55**	3.13
N_d (deviation)		2	385.12	0.46	1015.54	50.28**
Error a	16		635.55	1.83	535.32	2.36
Hybrids (H)	20		1302.89**	20.16**	1336.52**	18.48**
H x N	80		131.02**	0.67**	194.76**	1.11**
H x N_ℓ		20	233.73**	1.60**	293.22**	2.81**
H x N_q		20	98.72	0.47	246.92**	0.66*
H x N_d		40	239.55**	0.75**	298.64**	1.20**
Error b	400		81.16	0.31	90.84	0.35
Total	524					
C.V. %			9.62	4.04	12.17	4.54

[a]Values were multiplied by 10^2.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

all experiments. A significant interaction existed between applied N and hybrids, excepting the portion of the CW-77 data involving the 21 hybrids common to all three site-years.

A highly significant quadratic response in %N in the grain to applied N was observed in all of the experiments except in CW-78 where the response was linear. This exception may be due in large part to the large response to the lower rates of applied N and the possible failure to use enough N rates to adequately measure the response to N. The differences in the observed N percentages among hybrids were highly significant in all experiments. There was also a highly significant interaction between applied N and hybrids in all experiments.

Applied N had no effect on the P percentage in the grain in the CW-77 experiment where the available P in the soil was very high. In the A-76 experiment where the available soil P was relatively low, the main effect of N on P percentage in the grain was not significant but a significant quadratic effect was noted. This latter effect was very consistent among hybrids and was probably related to the sharp increase in yield resulting from the first increment of applied N which caused some dilution in the P content of the grain.

In conclusion, the acceptability of the quadratic regression model for use in determination of maximum yield is indicated by the significant quadratic yield responses to applied N in all experiments as shown in Tables 4, 5, and 6, and by the regression coefficients shown in Appendix Tables A1, A4, A7, and A9.

For illustrative purposes, the observed and predicted grain yields,

%N, and %P values for the 12 pedigree single crosses common to the A-76 and CW-77 experiments are shown graphically in Figures 1 and 2, respectively. Since the same 12 single crosses are used in each figure, some meaningful comparisons bewteen the responses in the two experiments can be made that would not be possible if all 26 hybrids were shown for the A-76 experiment and all 30 single crosses were shown for the CW-77 experiment. It should be pointed out, however, that the curves for these 12 single crosses in both site-years represent quite well the response curves that would be obtained if all of the hybrids had been shown in each site-year.

It is apparent that the predicted yield curve for the 12 single crosses in the A-76 experiment does not fit the observed mean yields (Figure 1) as well as for the CW-77 experiment (Figure 2). The divergence between the predicted yield curve and the mean data points for the A-76 experiment is explained in large part by some erratic yield responses of hybrids B75 x A632, N7A x Mo17, and Oh545 x A632 (Appendix Table A1). Figures 1 and 2 also illustrate that the yield response curves for the two experiments and the %N curve for the CW-77 experiment are quadratic. The %N curve for A-76, however, is only slightly quadratic (significant at the 5% level) and it shows a luxury consumption of N in the zone above maximum yield. This luxury consumption is probably associated with the dry weather conditions experienced during the grain-filling period, for Miranda (1981) has found that very high moisture stress results in considerable luxury consumption of N as well as in high critical %N values. Under such conditions errors in estimating the maximum

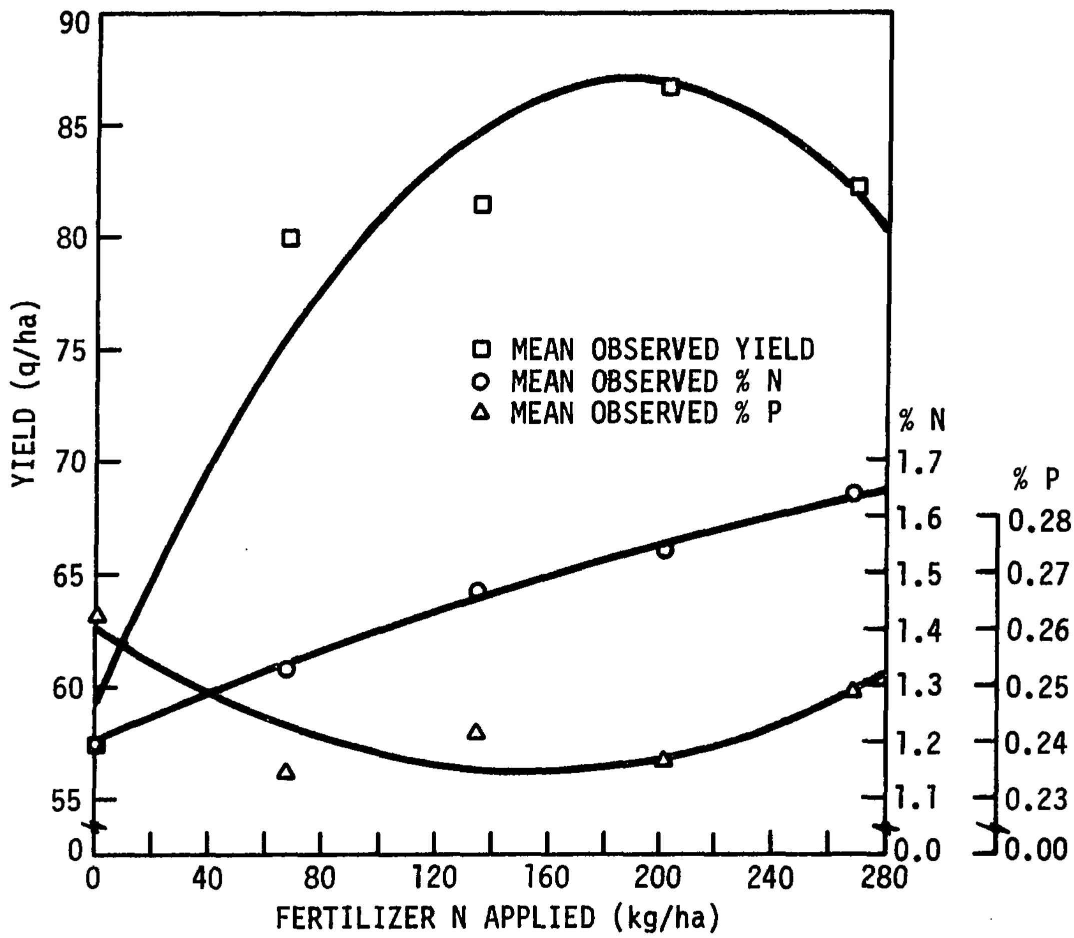

Figure 1. The observed and predicted grain yields, %N values, and %P values for 12 maize pedigree single crosses in the A-76 experiment

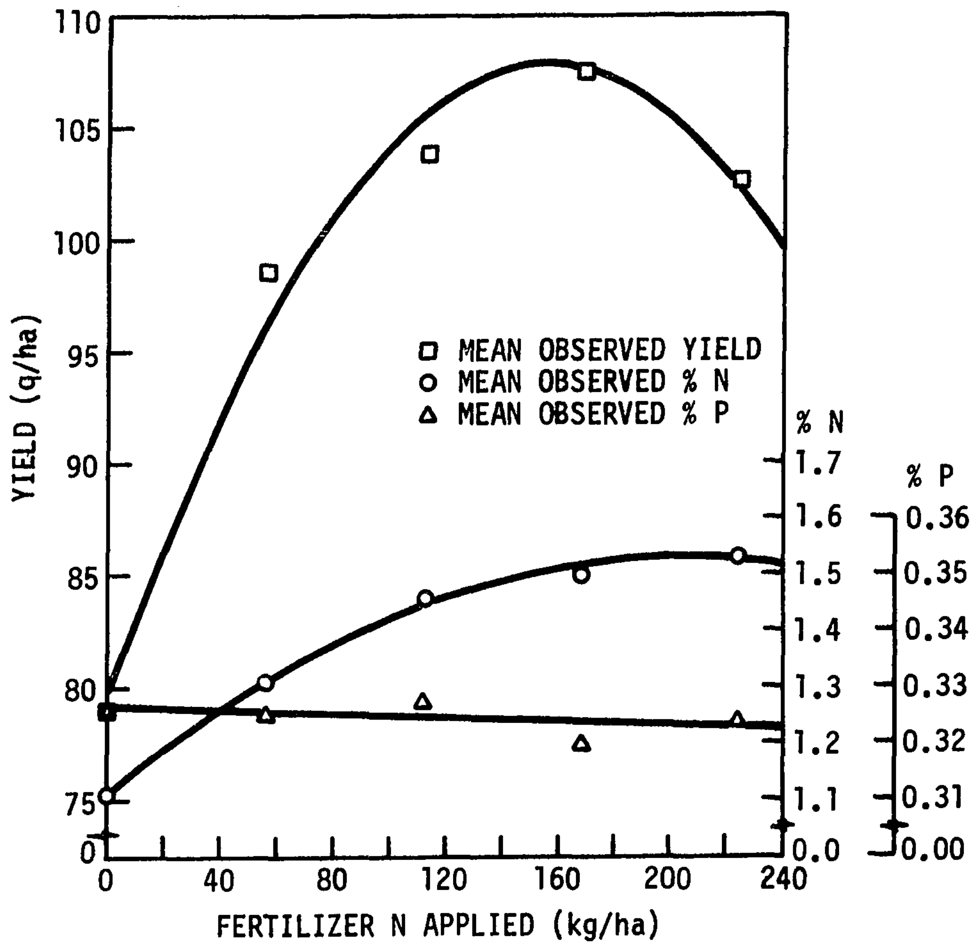

Figure 2. The observed and predicted grain yields, %N values, and %P values for 12 maize pedigree single crosses in the CW-77 experiment

yield will result in less precise critical %N values than where there is less luxury consumption, as was found in the CW-77 experiment.

Differences in Critical N Percentages Among the Hybrids

Table 7 presents the mean squares from the analyses of variance for critical %N values, maximum yields, and associated P percentages in the grain for the 12 pedigree single crosses used in the A-76 and CW-77 experiments. The differences among the 12 single crosses in each of these three parameters were highly significant. The mean squares from the analyses of variance for critical %N values and maximum yields of the grain for the 21 pedigree single crosses used in CW-77, A-78, and CW-78 experiments are shown in Table 8. There was a highly significant difference among these hybrids in both the critical %N and maximum yield.

The critical %N values, maximum yields, and associated P percentages in the grain for the 14 commercial hybrids (A-76) are shown in Table 9. The critical %N, maximum yields, and associated P percentages in the grain for the 12 pedigree single crosses used in the A-76 and CW-77 experiments are shown in Table 10. Table 11 shows the critical %N values for the 21 pedigree single crosses used in the CW-77, A-78, and CW-78 experiments. The critical %N in the grain for the various hybrids differed significantly, ranging from 1.42 to 1.73 %N for the 14 commercial hybrids in A-76 (Table 9); from 1.39 to 1.73 %N and from 1.35 to 1.71 %N for the 12 pedigree single crosses in A-76 and CW-77, respectively (Table 10); and from 1.25 to 1.66 %N, from 1.36 to 1.71 %N,

Table 7. Analyses of variance for the predicted critical %N values, maximum yields, and associated P percentages in the grain for 12 maize single crosses used in the A-76 and CW-77 site-years

Source	d.f.	Mean squares		
		Crit. %N[a]	Max. yield	Assoc. %P[b]
Site-year	1	1.26*	2831.85**	455.01**
Hybrids	11	2.73**	92.04**	7.65**
Error	11	0.15	19.90	0.81
Total	23			
C.V. %		2.56	4.55	3.21

[a]Values were multiplied by 10^2.

[b]Values were multiplied by 10^4.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

Table 8. Analyses of variance for predicted maximum grain yield and critical %N values of the grain of 21 maize single crosses used in the CW-77, A-78, and CW-78 site-years

Source	d.f.	Mean squares	
		Max. yield	Crit. %N[a]
Site-years	2	471.64**	1.09**
Hybrids	20	197.74**	3.66**
Error	40	31.95	0.18
Total	62		
C.V. %		5.39	2.85

[a]Values were multiplied by 10^2.

**Represents statistical significance at 1 percent level of probability.

Table 9. Critical %N values, maximum yields, and associated P percentages in the grain for 14 commercial maize hybrids used in the A-76 experiment

Hybrid	Crit. %N	Max. yield (q/ha)	Assoc. %P
Ames Best SX37	1.60	68.9	.255
DeKalb XL43	1.46	80.1	.244
DeKalb XL64	1.47	83.4	.239
DeKalb XL75	1.44	88.9	.201
Funks G4321A	1.55	76.4	.231
Iowa State M116A	1.50	81.7	.231
NK PX50A	1.59	72.4	.241
NK PX74	1.42	99.5	.212
Pioneer 3780	1.57	80.3	.235
Trojan TXS94	1.51	72.7	.231
Trojan TXS99	1.73	72.1	.289
Trojan TXS108A	1.62	86.8	.247
Trojan TXS113	1.44	89.8	.212
Trojan TXS119	1.63	90.6	.216
Mean	1.54	81.7	.235

Table 10. Critical %N values, maximum yields, and associated P percentages in the grain for 12 pedigree single crosses used in the A-76 and CW-77 experiments

Hybrid	Critical %N			Maximum yield (q/ha)			Associated %P		
	A-76	CW-77	Mean[a]	A-76	CW-77	Mean[a]	A-76	CW-77	Mean[a]
A632 x Oh551	1.73	1.66	1.70	75.9	100.8	88.4	.279	.367	.323
B75 x A632	1.65	1.52	1.58	89.8	104.4	97.1	.244	.322	.283
B70 x B14A	1.66	1.71	1.68	89.4	118.0	103.7	.253	.351	.302
B14A x B77	1.67	1.66	1.66	88.4	112.3	100.4	.250	.354	.302
B75 x B37	1.51	1.46	1.48	88.3	105.6	97.0	.223	.317	.270
B77 x B37	1.54	1.45	1.50	94.0	114.6	104.3	.223	.313	.268
B37 x B70	1.48	1.42	1.45	95.2	112.7	104.0	.225	.323	.274
Oh545 x A632	1.48	1.35	1.42	74.1	106.9	90.5	.250	.311	.281
Mo17 x N7A	1.43	1.39	1.41	88.5	105.6	97.1	.221	.308	.275
B70 x B73	1.46	1.47	1.46	94.6	124.5	109.6	.224	.320	.272
A631 x A239	1.40	1.40	1.40	81.3	94.0	87.7	.225	.307	.266
B73 x A619	1.39	1.36	1.38	87.3	106.3	96.8	.221	.290	.256
Mean[b]	1.53	1.49	1.51[c]	87.2	108.8	98.0[c]	.236	.324	.280[c]

[a]The standard errors for the hybrid means are 0.027 for the critical %N values, 3.15 for the maximum yields, and 0.0064 for the associated P percentages.

[b]The standard errors for the site-year means are 0.011 for the critical %N values, 1.29 for the maximum yields, and 0.0026 for the associated P percentages.

[c]The standard errors for the grand means are 0.008 for the critical %N values, 0.91 for the maximum yields, and 0.0018 for the associated P percentages.

Table 11. The critical %N values of the grain for 21 pedigree single crosses for the CW-77, A-78, and CW-78 experiments

Hybrid	Critical %N			
	CW-77	A-78	CW-78	Mean[a]
B14A x B75	1.61	1.63	1.52	1.59
B14A x B76	1.50	1.57	1.55	1.54
B14A x B77[b]	1.66	1.63	1.71	1.67
B14A x A619	1.63	1.58	1.56	1.59
B14A x Va26	1.58	1.68	1.64	1.63
B14A x N7A	1.52	1.56	1.64	1.57
Mo17 x B75	1.61	1.63	1.69	1.64
Mo17 x B76	1.37	1.40	1.40	1.39
Mo17 x B77	1.54	1.59	1.60	1.58
Mo17 x A619	1.48	1.44	1.37	1.43
Mo17 x Va26	1.43[c]	1.47[c]	1.54	1.48
Mo17 x N7A[b]	1.39	1.46	1.49	1.45
B73 x B75	1.43	1.48	1.36	1.42
B73 x B76	1.33	1.34	1.37	1.35
B73 x B77	1.36	1.42	1.40	1.39
B73 x A619[b]	1.36	1.35	1.39	1.37
B73 x Va26	1.36	1.43[d]	1.41	1.40
B73 x N7A	1.25	1.42	1.37	1.35
B14A x Mo17	1.65	1.69[d]	1.61	1.65
B14A x B73	1.55	1.63	1.64	1.61
Mo17 x B73	1.38	1.49	1.46	1.44
Mean[d]	1.48	1.52	1.51	1.50[e]

[a]The standard error for the hybrid means is 0.025.

[b]Critical %N values for these 3 single crosses were also obtained in the A-76 experiment. The values were: 1.67% for B14A x B77, 1.43% for Mo17 x N7A, and 1.39% for B73 x A619.

[c]These values were determined by the graphical method.

[d]The standard error for the site-year means is 0.009.

[e]The standard error for the grand mean is 0.005.

and from 1.34 to 1.69 %N for the 21 pedigree single crosses in CW-77, A-78, and CW-78, respectively (Table 11).

These ranges in critical %N are in general agreement with the N percentage values reported by Russell and Pierre (1980) for widely-used pedigree hybrids grown at high levels of N sufficiency at two different sites. The range in N percentages among the 52 single crosses grown at one site was from 1.35 to 1.80 %N, and the range for the 49 single crosses grown at the second site was from 1.39 to 1.85 %N. These values are not strictly comparable to the critical N percentages obtained in this study, since they represent values from only one rate of N, but they are of interest because of the larger number of hybrids represented.

In general, the range in the critical %N values found in these experiments are equivalent to a range in crude protein in maize grain of about 2.0 to 2.5%. This magnitude would have practical significance to maize producers and cattle feeders, and might also be of interest to maize processors. Moreover, it is recognized that through maize breeding these differences can be materially increased (see Part II of this thesis).

Effect of Site-year on the Critical %N in Different Hybrids

The average critical %N values in the grain of the 12 pedigree single crosses for the two site-years were 1.53% for A-76 and 1.49% for CW-77. The standard error of the difference is 0.016 for the two means. These site-year means were significantly different at the 5% level (Table 7).

The influence of site-year, however, was small compared with the influence of hybrids. The correlation coefficient for the critical %N values between the two years was 0.90**. This relationship is shown in Figure 3.

The critical %N values in the grain of the 21 pedigree single crosses used in CW-77, A-78, and CW-78 are shown in Table 11. The average critical %N values for these 21 hybrids for the three site-years were 1.48% for CW-77, 1.52% for A-78, and 1.51% for CW-78. The standard error of the difference was 0.013 for these means. These site-year means differed significantly at the 1% level (Table 8). As with the 12 single crosses, the influence of site-year was small compared with the influence of hybrids. Again, the correlations between site-years were highly significant for critical %N in the grain. The coefficients between CW-77 and A-78 was 0.90**; between CW-77 and CW-78, 0.83**; and between A-78 and CW-78, 0.87**. Thus, the mean correlation coefficient was 0.87**.

It is recognized that these differences between site-years might be greater under a wider range of environmental conditions. Recently, Miranda (1981) found that severe drought increases the critical N percentage, and that low P sufficiency decreases it. In the present experiments, the available soil P ranged from low-medium to very high and the moisture-stress index ranged from nil to moderate (Table 1). However, no evidence was obtained in these experiments that differences in soil P availability or of slight to moderate differences in moisture stress were responsible for the differences in critical %N in different

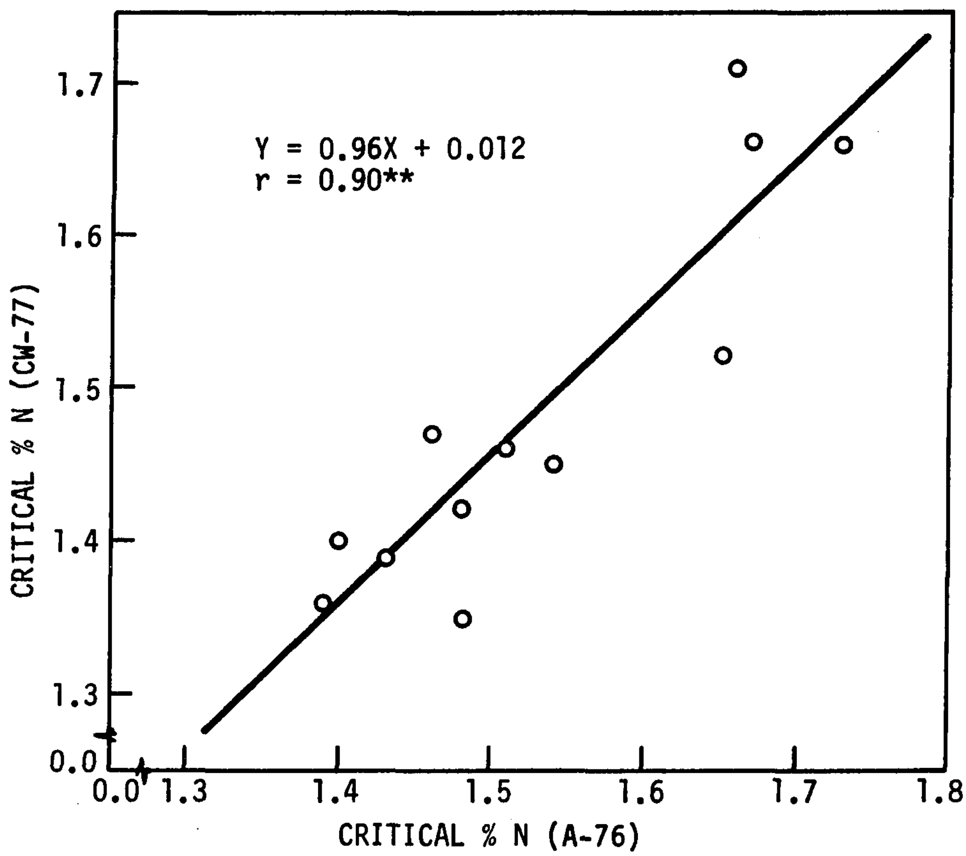

Figure 3. Relationship between the critical %N values for the 12 maize pedigree single crosses used in 2 site-years

site-years. It must be recognized, however, that only 4 site-years were involved in this study.

Relationships of Critical %N with Associated P Percentage, and Maximum Yield

Tables 9 and 10 present the associated P percentages in the grain for 14 commercial hybrids of A-76 and for 12 pedigree single crosses used in the A-76 and CW-77 experiments, respectively. A highly significant difference in associated P percentages among the 12 single crosses was observed (Table 7). There was also a highly significant difference in associated P percentages between site-years, as would be expected from the large difference in soil available P between the two sites (Table 1).

In spite of the large difference in available soil P levels (and the resulting associated P percentages) between the two sites, there was a highly significant, positive correlation in both site-years between the critical %N values and associated P percentages for the 26 hybrids in the A-76 experiment and the 30 in the CW-77 experiment. The relationship between these two predicted parameters is shown graphically for each site-year in Figure 4. The correlation coefficients were 0.76** for A-76 and 0.83** for CW-77. It is noteworthy that this relationship holds despite the high P percentages in the grain in 1977 and relatively low P percentages in 1976.

The correlation coefficient between the maximum yields and critical %N values for the 26 hybrids in the A-76 experiment was -0.32 and for

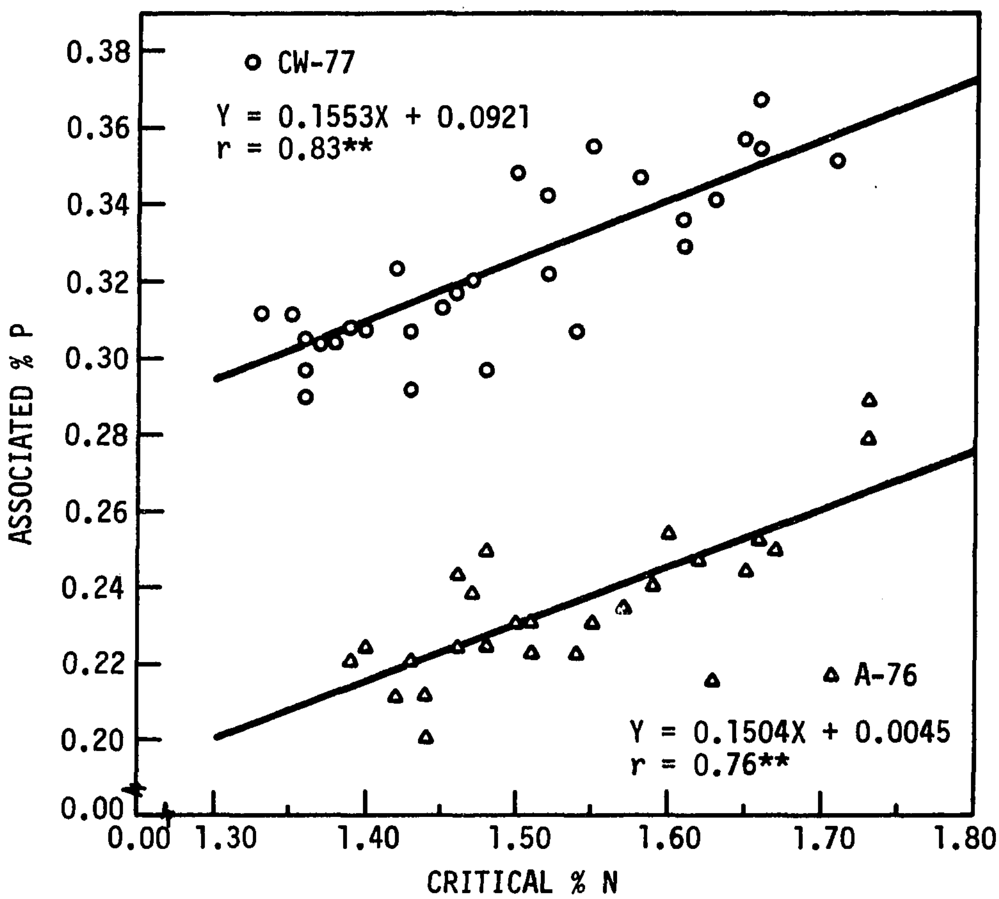

Figure 4. Relationship between critical %N and associated P percentage in the grain of 26 hybrids in the A-76 experiment and of 30 hybrids in the CW-77 experiment

the 30 hybrids in the CW-77 experiment, -0.24. For the 21 single crosses common to CW-77, A-78, and CW-78 the correlation coefficients were -0.37, 0.10, and -0.37, respectively (Tables 11 and 12). These two parameters tended to be negatively correlated but the correlations were not significant under these conditions where sufficient N was available for maximum yield of all of the hybrids. The negative correlation reported in the literature may have been due to the fact that only one level of N was used. Under such a condition some of the high-yielding hybrids may have been relatively low in N percentage because of a greater insufficiency of N than the low-yielding hybrids, and/or the low-yielding hybrids relatively high because of greater sufficiency.

Table 12. The maximum grain yields for 21 pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Hybrids	Maximum grain yields (q/ha)			
	CW-77	A-78	CW-78	Mean[a]
B14A x B75	110.8	115.2	110.9	112.3
B14A x B76	105.4	101.9	94.9	100.7
B14A x B77	112.3	106.3	96.6	105.1
B14A x A619	95.1	104.9	97.3	99.1
B14A x Va26	91.3	107.3	93.4	97.3
B14A x N7A	101.6	96.5	92.1	96.7
Mo17 x B75	105.6	99.9	105.5	103.7
Mo17 x B76	111.0	101.6	112.7	108.4
Mo17 x B77	110.7	106.3	96.5	104.5
Mo17 x A619	86.3	89.4	86.2	87.3
Mo17 x Va26	116.3[b]	102.2[b]	99.3	105.9
Mo17 x N7A	107.4	102.8	102.2	104.1
B73 x B75	126.3	116.8	115.7	119.6
B73 x B76	111.3	104.4	101.6	105.8
B73 x B77	128.7	114.3	105.3	116.1
B73 x A619	106.3	107.4	101.0	104.9
B73 x Va26	116.6	101.4[b]	90.3	102.8
B73 x N7A	113.9	100.5	108.7	107.7
B14A x Mo17	119.3	116.3[b]	104.2	113.3
B14A x B73	103.9	90.3	80.2	91.5
Mo17 x B73	126.4	112.9	113.1	117.5
Mean[c]	109.8	104.7	100.4	105.0[d]

[a]The standard error for the hybrid means is 3.26.

[b]These values were determined by the graphical method.

[c]The standard error for the site-year means is 1.23.

[d]The standard error for the grand mean is 0.71.

SUMMARY AND CONCLUSIONS

The objectives of this part of the study were: (1) to determine the extent to which commercial hybrids and pedigree hybrids differ in their critical %N, (2) to determine the constancy of the critical %N values for various hybrids in different site-years, and (3) to examine the relationship between the critical %N and the associated P percentages for different hybrids in different site years.

The experiments consisted of four randomized complete block, split-plot experiments involving four site years. A total of 14 commercial hybrids and 30-pedigree single crosses were used in the experiments. Twelve hybrids common to 2 site-years and 21 common to 3 site-years provided a range of genetic materials for year-to-year comparison.

The maize hybrids responded significantly to N fertilizers in both yield and N percentage in the grain in all four site years. The differences among hybrids in yield and in N percentage were highly significant in all experiments. A highly significant interaction between N rates was observed for each of the measured parameters in each of the experiments.

Critical %N

The ranges in critical %N among commercial hybrids and pedigree single crosses were quite similar. The 14 commercial hybrids ranged in critical %N from 1.42 to 1.73%N (A-76), whereas the 12 pedigree single crosses ranged from 1.39 to 1.73%N (A-76) and 1.35 to 1.71%N (CW-77). The 21 single crosses ranged in critical %N from 1.25 to

1.66%N (CW-77), and from 1.36 to 1.71%N (A-78), and 1.34 to 1.69%N (CW-78). These results mean: (1) that before critical %N can be generally useful in N nutrition studies and in diagnostic work, the critical %N values for the hybrid or hybrids involved should be known, and (2) that critical %N values or their equivalent, the optimal protein percentages, provide a valid basis for comparing maize hybrids for their protein feeding value.

Site-Year Differences

Although the critical %N in the grain of the 12 pedigree single crosses for 2 site-years (1.53%N in A-76 and 1.49%N in CW-77) and of the 21 pedigree single crosses for 3 site-years (1.48%N in CW-77, 1.51%N in A-68, and 1.52%N in CW-78) were significantly different, the differences due to years were small compared to the differences due to hybrids. The critical %N values of the hybrids for the different years were highly correlated. The correlation coefficient between the 2 site-years for the 12 single crosses was 0.90**; and among the 3 site-years for the 21 single crosses the coefficients ranged from 0.83** to 0.90**, with a mean correlation coefficient of 0.87**.

No evidence was obtained in these experiments that differences in soil P availability or of slight to moderate differences in moisture stress were responsible for the difference in critical %N in different site-years.

Associated P Percentages

The hybrids also differed significantly in the predicted associated P percentages in each of the two experiments that included this parameter

(A-76 and CW-77). Highly significant correlations were obtained between critical %N and the associated P percentage, the r values being 0.76 for A-76 and 0.83 for CW-77. From a livestock feeding viewpoint, it means that hybrids that are high in optimal protein percentages also tend to be high in P percentage.

PART II. THE RELATIONSHIP BETWEEN THE CRITICAL NITROGEN PERCENTAGES OF MAIZE SINGLE CROSSES AND THEIR PARENTAL INBREDS

INTRODUCTION

The results obtained in Part I showed that maize hybrids differ significantly in critical %N, with individual values ranging from about 1.30 to 1.70% in the various experiments. This means that before the N percentage in corn grain can be used as a measure of N sufficiency in the plant, critical %N values will be needed. Moreover, such values, or the equivalent protein percentages, will be needed if hybrids are to be characterized for their protein-feeding value at maximum yields (optimal % protein). If a high genotypic relationship between the critical %N of single crosses and their parental inbreds exists, such information would greatly expedite determining the critical %N of hybrids (Russell and Pierre, 1980).

Russell and Pierre (1980) reviewed the literature relating to differences among genotypes, and examined the possibility of predicting the critical %N of hybrids from that of their parental lines. They corroborated results from Genter et al. (1957) and Pollmer et al. (1978), showing that the N percentage in the grain of maize single crosses was highly correlated with that of the mean of the parental inbreds, and they concluded that the relative values for N percentage among hybrids can be predicted reasonably well from the mean N percentage of the two parents. All these investigations, however, were conducted at only one level of N and not necessarily at maximum yield for the different genotypes. Some of the genotypes, therefore, were probably at different levels of N sufficiency, with some of the relatively high-yielding hybrids showing low values and the low-yielding hybrids high values. No investigations have been reported in which the relationship between the critical %N of single crosses and of their parental inbreds have been determined.

The objectives of this study were:

(1) To determine the relationship between the critical %N of hybrids and of their parental inbreds, and

(2) To estimate the extent to which the critical %N of hybrids can be predicted from the mean of the critical %N of the parental inbreds.

PLANS AND PROCEDURES

This study involved data from two field experiments conducted in 1978. One experiment was located at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa (A-78), and the other was located at the Clarion-Webster Research Center near Kanawha, Iowa (CW-78). Both of the experiments included 21 pedigree single crosses and 9 inbreds of maize. A presentation of some of the data for the 21 single crosses was made in Part I. The soil description, the initial soil-test levels, and the moisture-stress index for maize (Shaw, 1974) for each of the experiments are shown in Table 1 (Part I). The CW-78 experiment was located on the same site as the CW-77 experiment reported in Part I, while soybeans were grown on the A-78 site in 1977.

Each experiment involved a replicated randomized complete block, split-plot design in which N treatments were the main experimental units, and maize single crosses and inbreds were the subunits. The main plots were 6 meters wide by 23 meters long and the subunits consisted of a single 6-meter row of each hybrid (or inbred), in 76-centimeter row spacing. Several border rows were planted around the outside of the experimental area.

The rates of N were 0, 56, 112, 168, and 224 kg/ha in both experiments, with granular urea (46-0-0) being used as the source of N. The urea was broadcast by hand immediately after planting and the plots were harrowed very lightly to incorporate the fertilizer. At the CW-78 site the N treatments were reapplied to plots which had received equivalent rates in the CW-77 experiment. Satisfactory weed control was accomplished with the use of recommended herbicides and some hand hoeing.

The inbreds and single-cross hybrids were each planted in blocks within a main plot rather than being completely randomized. This practice was used to minimize the competitive effect of different sized plants growing adjacent to each other. In most of the statistical analysis of the data and in the subsequent discussion, these two groups of genetic material are for all practical purposes considered as two separate experiments at each site.

The 9 inbreds chosen for this study were the parental lines of the 21 hybrids listed in Table 2, Part I. The hybrids consisted of single crosses in which B14A, Mo17, and B73 were used as parental inbred testers. Crosses of each of these testers with 6 parental inbred lines were selected. The parental inbred lines were B75, B76, B77, A619, Va26, and N7A. The remaining 3 single crosses represented crosses between the 3 parental inbred testers. The selection of these single crosses was based on evidence that hybrids containing B14A have relatively high N percentages in the grain, hybrids containing B73 have low N percentages, and hybrids containing Mo17 are intermediate in N percentages (Russell and Pierre, 1980; W. H. Pierre, Agronomy Department, Iowa State University, Ames, Iowa, unpublished data).

The cultural practices, harvesting and processing procedures, nutrient analyses, and statistical analyses and computations were the same as those described for the experiments in Part I. The P percentages were not determined for the grain samples from the 1978 experiments.

Correlation analysis was used in this study to evaluate the relationship between the critical %N in the grain of the single crosses and the critical %N of the parental inbreds.

RESULTS AND DISCUSSION

The environmental conditions were quite favorable for maize production in the CW-77, A-78, and CW-78 experiments, as indicated by the low moisture-stress indexes shown for these experiments in Table 1 (Plans and Procedures, Part I). Relatively high grain yields were obtained for the 21 maize pedigree single crosses, averaging approximately 105 q/ha in CW-77 and 100 q/ha in A-78 and CW-78 for the higher N treatments. Grain yields for the 9 parental inbreds grown in the A-78 and CW-78 experiments averaged approximately 50 q/ha in both site-years.

The observed grain yields and N percentages (%N) for the 21 pedigree single crosses common to the CW-77, A-78, and CW-78 experiments (listed in Table 2, Part I) are shown in Appendix Tables A4, A5, and A7 through A10. Since the CW-78 experimental site was the same as the one used for the CW-77 experiment (discussed more fully in Part I) and the control plots had received no N either year, the control yields were very low in 1978 and a yield response of approximately 60 q/ha was obtained. The yield response was about 25 to 30 q/ha in the CW-77 and A-78 experiments. The analyses of variance for the observed grain yields and %N values for the 21 single crosses was presented in Table 6 and discussed in Part I. A highly significant quadratic response in observed grain yield and %N to applied N was measured in all experiments, except in CW-78 where the %N response was linear.

The 21 pedigree single crosses mentioned above consisted of combinations of 9 inbreds (referred to as parental inbreds). The observed grain yields and %N values for the 9 parental inbreds, grown in the A-78 and CW-78 experiments, are shown in Appendix Tables A11 through A14, and the mean squares from the analyses of variance for these data are shown in Table 13. A highly significant quadratic response in observed grain yields and %N values to applied N was obtained for the parental inbreds in A-78 and CW-78. The differences among the parental inbreds in observed grain yield and %N were highly significant in both experiments. The interaction between N rates and inbreds was highly significant for only the %N in the grain in both experiments.

The two-step regression method (described in the Plans and Procedures, Part I) was used to compute the maximum yield and critical %N in the grain of each single cross and parental inbred within each experiment individually.

Differences in Critical N Percentages Among Genotypes

Hybrid

The critical %N and maximum yields of grain for the 21 maize pedigree single crosses were presented in Tables 11 and 12 (Part I) for each of the experiments (CW-77, A-78, and CW-78). These single crosses differed significantly (at the 1% level) in critical %N and maximum yield (Table 8, Part I). A highly significant difference in critical %N, as well as maximum yield were observed among the 3 site-years. However, the influence of site-year on critical %N was small compared to that of hybrids. The mean coefficient was 0.87** for the correlation of the critical %N values between site-years.

Table 13. Analysis of variance for observed grain yield and %N for the 9 maize parental inbreds used in the A-78 and CW-78 experiments

Source of variation	d.f.	Mean squares			
		A-78		CW-78	
		Yield	N percent[a]	Yield	N percent[a]
Replications (R)	4	174.20	0.92	57.87	4.43*
Nitrogen (N)	4	468.51**	70.88**	5339.91**	199.00**
N_ℓ (linear)	1	1271.00**	248.57**	16380.93**	734.21**
N_q (quadratic)	1	496.90**	31.62**	4571.92**	58.21**
N_d (deviation)	2	53.07	1.67	203.39*	1.79
Error a	16	66.74	1.03	52.08	1.39
Inbreds (I)	8	2255.99**	112.92**	1814.89**	83.80**
I x N	32	62.23	1.62**	61.59	2.08**
I x N_ℓ	8	55.73	5.79**	79.51	4.61**
I x N_q	8	80.59	0.31	113.61*	1.98**
I x N_d	16	56.30	0.20	26.62	0.86
Error b	160	44.10	0.31	65.75	0.57
Total	224				
C.V.%		14.90	3.13	18.76	4.50

[a]These values were multiplied by 10^2.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

Eighteen of the 21 pedigree single crosses (the first 18 listed in Table 2, Part I, used in the CW-77, A-78, and CW-78 experiments) were composed of 3 parental inbreds (B14A, Mo17, and B73), which are referred to as parental inbred testers, and 6 parental inbreds (B75, B76, B77, A619, Va26, and N7A), which are referred to as parental inbred lines. The average critical %N values and maximum yields of grain for these 18 single crosses are presented in Table 14. This summary table facilitates the evaluation of the influence of the 3 parental inbred testers and 6 parental inbred lines on critical %N and maximum yield. The mean squares from the analyses of variance of the critical %N values and maximum yields for these 18 single crosses are shown in Table 15. For both the critical %N and maximum yields, the differences among the 3 parental inbred testers are highly significant, as are also the differences among the 6 parental inbred lines within testers. As shown in Table 14, the mean critical %N for the 6 hybrids containing B14A as the parental inbred tester was 1.60%, while the mean critical %N values for the hybrids containing Mo17 and B73 as the parental inbred testers were 1.49% and 1.38%, respectively. The standard error for these 3 parental inbred tester means was 0.010. The mean critical %N for the 3 hybrids containing either B75 or B77 as the parental inbred line was 1.55%, while for the 3 hybrids containing Va26, A619, N7A, and B76 as the parental inbred lines had a mean critical %N of 1.50, 1.46, 1.46, and 1.43%, respectively. The standard error for these 6 parental inbred line means was 0.015.

Table 14. Average critical %N and maximum yields of the grain for 18 of the maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments, averaged by parental inbred testers and lines across the 3 site-years

Parental inbred line	Critical %N				Maximum yield (q/ha)			
	Parental inbred tester			Mean[a]	Parental inbred tester			Mean[a]
	B14A	Mo17	B73		B14A	Mo17	B73	
B75	1.59	1.64	1.42	1.55	112.3	103.7	119.6	111.9
B76	1.54	1.39	1.35	1.43	100.7	108.4	105.8	105.0
B77	1.67	1.58	1.39	1.55	105.1	104.5	116.1	108.6
A619	1.59	1.43	1.37	1.46	99.1	87.3	104.9	97.1
Va26	1.63	1.48	1.40	1.50	97.3	105.9	102.8	102.0
N7A	1.57	1.45	1.35	1.46	96.7	104.1	107.7	102.9
Mean[b]	1.60	1.49	1.38	1.49[c]	101.9	102.3	109.5	104.6[c]

[a]The standard errors for the parental inbred line means were 0.015 for the critical %N values and 1.89 for the maximum yields.

[b]The standard errors for the parental inbred tester means were 0.010 for the critical %N values and 1.34 for the maximum yields.

[c]The standard errors were 0.006 for the critical %N grand mean and 0.77 for the maximum yield grand mean.

Table 15. Analyses of variance of the critical %N values and maximum yields of the grain for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Source of variation	d.f.	Mean squares	
		Critical %N[a]	Maximum yield
Site-years	2	0.75*	299.27**
Hybrids	17	3.62**	160.22**
Testers (T)	2	21.58**	326.76**
Lines (L)	5	2.36**	241.95**
T x L	10	0.66**	86.04*
Error	34	0.19	32.13
Total	53		
C.V.%		2.19	5.42

[a]These values were multiplied by 10^2.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

Inbreds

The critical %N values and maximum yields of grain for the 9 parental inbreds grown only in the A-78 and CW-78 experiments are shown in Table 16. The mean squares from the analyses of variance for these two parameters for both experiments are shown in Table 17. The differences among the 9 parental inbreds in critical %N and maximum yield were highly significant. A highly significant correlation (r-value = 0.93) was observed between the mean critical %N of these 9 parental inbreds and the mean %N for these same 9 inbreds reported by Russell and Pierre (1980). The average critical %N in the grain of the 9 parental inbreds ranged from 1.59% for B73 to 2.25% for B14A (Table 16), and the average %N reported by Russell and Pierre (1980) ranged from 1.45% for B73 to 2.21% for B14A. This indicates the %N values reported by Russell and Pierre (1980), which were obtained at only one level of N (a high level), were probably close to the values representing maximum yield, or the critical %N. This could be expected if inbreds show little luxury consumption of N. In the present experiments there was little or no luxury consumption for the parental inbreds (Appendix Tables A11 through A14).

Although there was a significant difference (at the 5% level) in critical %N between site-years, the correlation between the critical %N values of one site-year and those of the other site-year was highly significant, with a coefficient of 0.98. This correlation is shown graphically in Figure 5. This is explained by a fairly consistent but small difference in critical %N between the two site-years. Likewise, although there was a highly significant difference in maximum yield

Table 16. Critical %N values and maximum yields of grain for the 9 maize parental inbreds used in the A-78 and CW-78 experiments

Inbred	Critical %N			Maximum yield (q/ha)		
	A-78	CW-78	Mean[a]	A-78	CW-78	Mean[a]
B14A	2.28	2.21	2.25	27.4	32.6	30.0
B75	2.01[b]	1.95	1.98	47.4[b]	52.4	49.8
Mo17	1.89	1.86	1.88	38.9	49.7	44.3
B77	1.86	1.84	1.85	56.9	55.5	56.2
N7A	1.85	1.78	1.82	52.8	58.0	55.4
B76	1.80[b]	1.77	1.79	48.0[b]	54.1	51.0
Va26	1.72[b]	1.72	1.72	47.5[b]	45.7	46.6
A619	1.74	1.65	1.70	50.1	57.4	53.8
B73	1.57	1.60	1.59	62.6	68.2	65.4
Mean[c]	1.86	1.82	1.84[d]	47.9	52.6	50.3[d]

[a]The standard error for the inbred means was 0.019 for critical %N and 1.99 for maximum yield.

[b]These values were determined by the graphical method.

[c]The standard error for the site-year means was 0.009 for critical %N and 0.94 for maximum yield.

[d]The standard error for the grand means was 0.006 for critical %N and 0.66 for maximum yields.

Table 17. Analyses of variance of the critical %N values and maximum yields of the grain for the 9 maize parental inbreds used in the A-78 and CW-78 experiments

Source of variation	d.f.	Mean squares	
		Critical %N[a]	Maximum yield
Site-years	1	0.32*	49.47**
Inbreds	8	2.89**	76.33**
Error	8	0.07	7.93
Total	17		
C.V.%		1.47	5.60

[a]These values were multiplied by 10^2.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

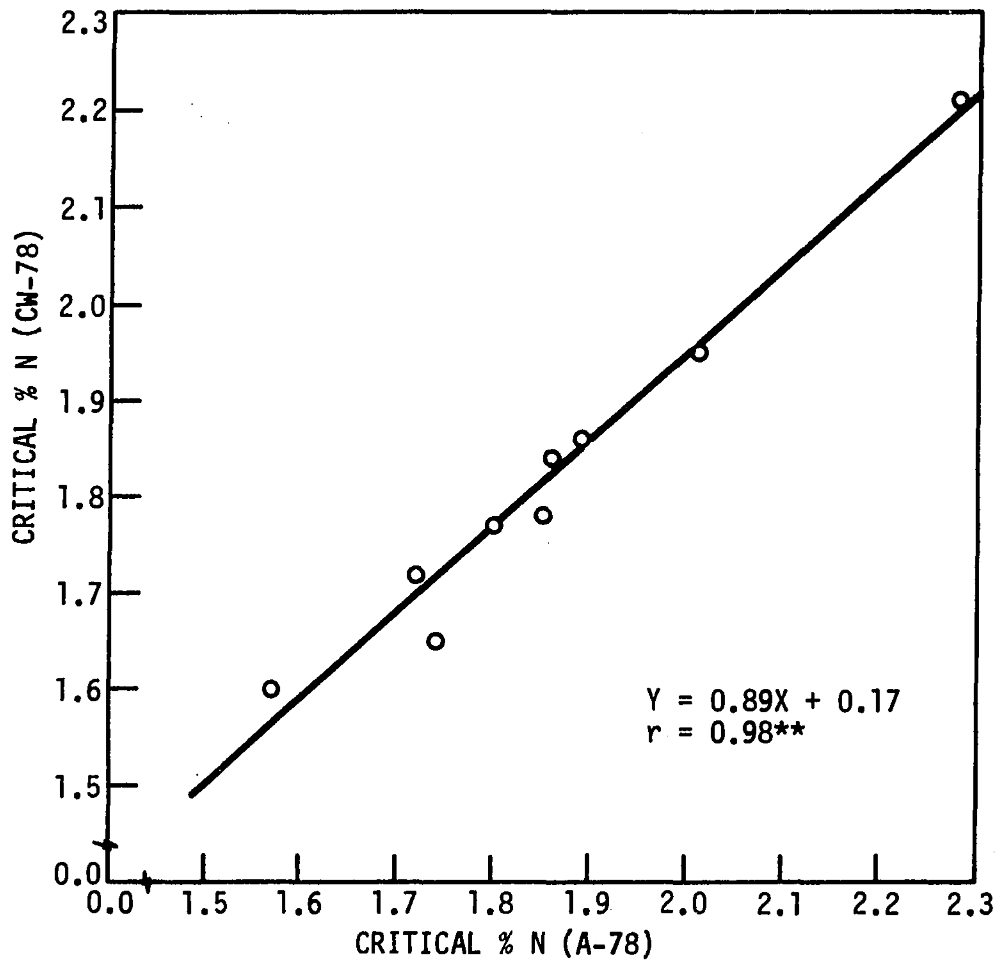

Figure 5. Relationship between the critical %N values in the grain for the 2 sites at which the 9 maize parental inbreds were grown in 1978

between site-years, the correlation between the maximum yields of one site-year and those of the other site-year was highly significant, with a coefficient of 0.92.

A highly significant inverse relationship was found between the critical %N values and the maximum yields of the grain for the 9 parental inbreds in both site-years (Figure 6), the mean correlation coefficient being -0.83**. This is in agreement with what Russell and Pierre (1980) found for 29 maize inbreds grown in 3 years at high levels of N. It is, however, in contrast with the non-significant, negative correlation between critical %N and maximum yields for the 21 pedigree single crosses (discussed in Part I) where the correlation coefficients ranged from +0.10 to -0.37. Some of the probable reasons for the difference between these single crosses and the parental inbreds in this relationship between critical %N and maximum yields are: (1) that some of the low-yielding parental inbreds, such as B14A, have a lower degree of pollination, resulting in fewer kernels per ear and therefore a higher N percentage than the kernels of well-filled ears (Brunson and Latshaw, 1934); and (2) that the parental inbreds had a much greater range in yield and %N than hybrids, and that some of the inbreds at the extreme ends of the range (Figure 6) may have had an undue influence on the relationship.

Relationship Between Hybrids and Parental Inbreds in Critical N Percentage

An evaluation of the relationship between the critical %N values for the 21 pedigree single crosses and for their parental inbreds can

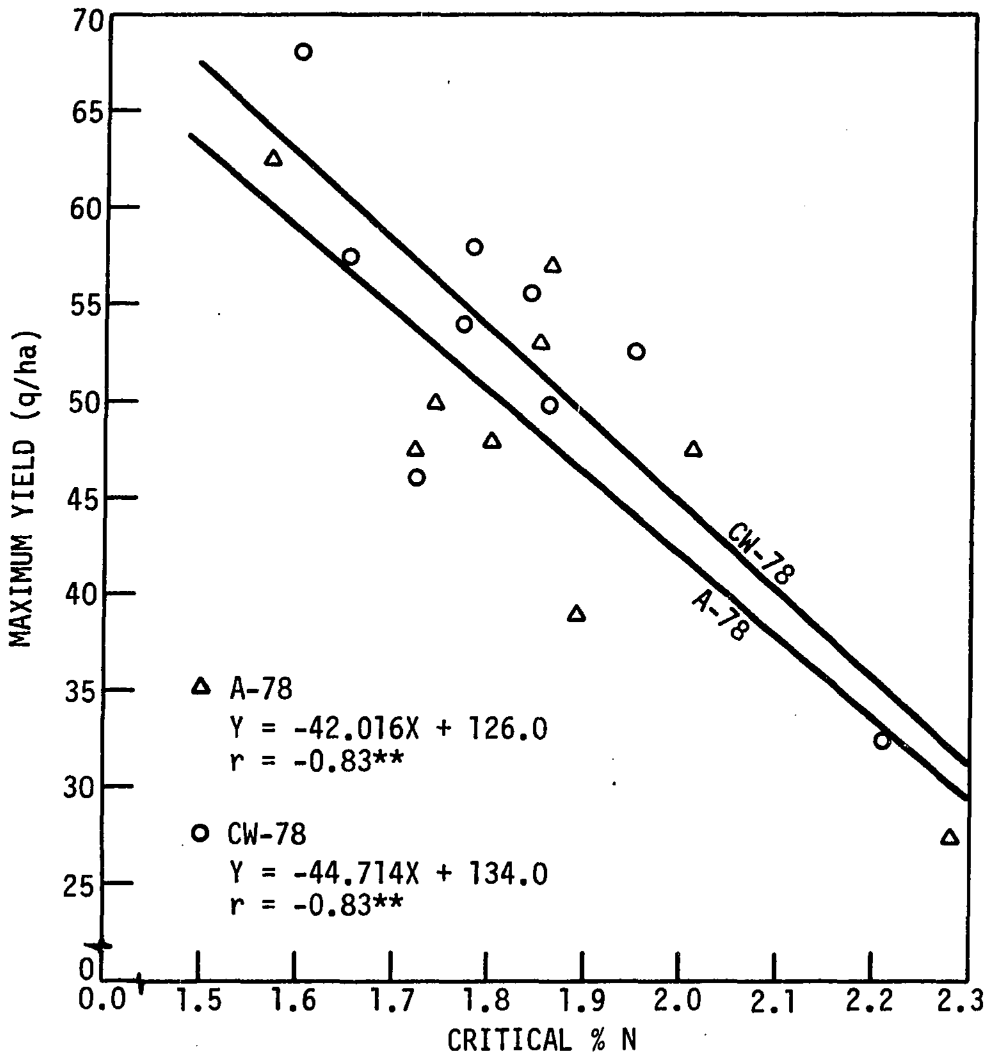

Figure 6. Relationship between critical %N and maximum yield of grain of the 9 parental inbreds grown at 2 sites in 1978

be facilitated by classifying the inbreds and hybrids into general groups or types based on their %N, as suggested by Russell and Pierre (1980). The 9 parental inbreds, grouped into 3 N types, are shown in Table 18 along with their critical %N values. Type A, high N, includes inbreds B14A and B75, and has a mean critical %N of 2.11; type B, intermediate N, includes inbreds B76, B77, Mo17, A619, and N7A, and has a mean of 1.79; and type C, low N, includes only B73 with a critical %N of 1.59.

Based on the N types of the parental inbreds in the crosses, the 21 single crosses were grouped into 4 types: AA, AB, BB or AC, and BC. Table 19 shows the critical %N of these single crosses according to this classification for the A-78 and CW-78 experiments. Also included in Table 19, is the mean critical %N of the parental inbreds used in the respective single crosses. It is evident that the critical %N values of the single crosses are related to the mean critical %N of their parental inbreds. This corroborates the findings of Russell and Pierre (1980), for there is very good agreement between the mean %N values of the respective groups of hybrids in their study and the critical %N values in this study. As they suggested, the arbitrary division of inbreds and single crosses into N types according to their critical %N values is apparently a useful way of characterizing maize genotypes for their optimum protein content. It is apparent, however, that some of the hybrids do not agree well with the other members of their respective N type. In part, this may have been because of the difficulty in some instances of obtaining accurate maximum yield data.

Table 18. Grouping by N-types, based on critical %N, of the 9 maize parental inbreds used at 2 sites in 1978

N-type	Inbred	Critical N percentage		
		A-78	CW-78	Mean
A	B14A	2.28	2.21	2.25
	B75	2.01[a]	1.95	1.98
	Mean	2.15	2.08	2.11
B	B76	1.80[a]	1.77	1.79
	B77	1.86	1.84	1.85
	Mo17	1.89	1.86	1.88
	A619	1.74	1.65	1.70
	Va26	1.72[a]	1.72	1.72
	N7A	1.85	1.78	1.82
	Mean	1.81	1.77	1.79
C	B73	1.57	1.60	1.59

[a]These values were determined by the graphical method.

Table 19. Relationship between critical %N in the grain of 21 maize pedigree single crosses and the mean critical %N in the grain of the parental inbreds grown at 2 sites in 1978

N-type	Hybrid	Critical N percentage			Mean critical %N of 2 parental inbreds		
		A-78	CW-78	Mean	A-78	CW-78	Mean
		%		%	%		%
AA	B14A x B75	1.63	1.52	1.58	2.15[b]	2.08	2.12
AB	B14A x B76	1.57	1.55	1.56	2.04[b]	1.99	2.02
	B14A x B77	1.63	1.71	1.67	2.07	2.03	2.05
	B14A x A619	1.58	1.56	1.57	2.01	1.93	1.97
	B14A x Va26	1.68	1.64	1.66	2.00[b]	1.97	1.99
	B14A x N7A	1.56	1.64	1.60	2.07	2.00	2.04
	B14A x Mo17	1.69	1.61	1.65	2.09	2.04	2.07
	Mo17 x B75	1.63	1.69	1.66	1.95[b]	1.91	1.93
	Mean	1.62	1.63	1.62	2.03	1.98	2.01
BB or AC	Mo17 x B76	1.40	1.40	1.40	1.85[b]	1.82	1.84
	Mo17 x B77	1.59	1.60	1.60	1.88	1.85	1.87
	Mo17 x A619	1.44	1.37	1.41	1.82	1.76	1.79
	Mo17 x Va26	1.47[a]	1.54	1.51	1.81[b]	1.79	1.80
	Mo17 x N7A	1.46	1.49	1.48	1.87	1.82	1.85
	B14A x B73	1.63	1.64	1.64	1.93	1.91	1.92
	B73 x B75	1.48	1.36	1.42	1.79[b]	1.78	1.79
	Mean	1.50	1.49	1.49	1.85	1.82	1.84
BC	B73 x B76	1.34	1.37	1.36	1.69[b]	1.69	1.69
	B73 x B77	1.42	1.40	1.41	1.72	1.72	1.72
	B73 x A619	1.35	1.39	1.37	1.66	1.63	1.65
	B73 x Va26	1.43[a]	1.41	1.42	1.65[b]	1.66	1.66
	B73 x N7A	1.42	1.37	1.40	1.71	1.69	1.70
	Mo17 x B73	1.49	1.46	1.48	1.73	1.73	1.73
	Mean	1.41	1.40	1.41	1.69	1.69	1.69
	Grand Mean	1.52	1.51	1.52	1.88	1.85	1.87

[a]These values were determined by the graphical method.

[b]One of two inbreds used in this average was determined by the graphical method.

It appears that hybrids containing B76 and A619 have lower critical %N values and hybrids containing B77 sometimes higher critical %N values than the others of their respective N groups. One hybrid, B14A x B73, seems to indicate a dominance of the high-N parental inbred (B14A) over the low-N parental inbred (B73). This may be due to differences in specific combining ability of the parental inbreds involved.

The correlation coefficients between the 21 single crosses and means of the parental inbreds for critical %N is 0.85** for the A-78 experiment and 0.79** for the CW-78 experiment, giving a mean correla-coefficient of 0.82**. This relationship is shown graphically in Figure 7. When the relationship between the critical %N of the 21 single crosses grown in the CW-77 experiment (Table 11, Part I) and the mean critical %N of the parental inbreds (obtained by averaging the mean critical %N of the parental inbreds grown in the A-78 and CW-78 experiments, and shown in Table 19) was examined, a correlation coefficient of 0.87** was obtained. These coefficients were slightly higher than those obtained by Russell and Pierre (1980).

In the A-78 experiment, the r-values between the critical %N values of the single crosses and those of the high and low inbreds are 0.85** and 0.60**, respectively (Table 20). Similar r-values for the CW-78 experiment were 0.73** and 0.62**, respectively. This supports, in general, the conclusions of Russell and Pierre (1980): (a) that there is little or no dominance in the inheritance of %N in the grain by maize single crosses, and (b) that gene action is primarily additive

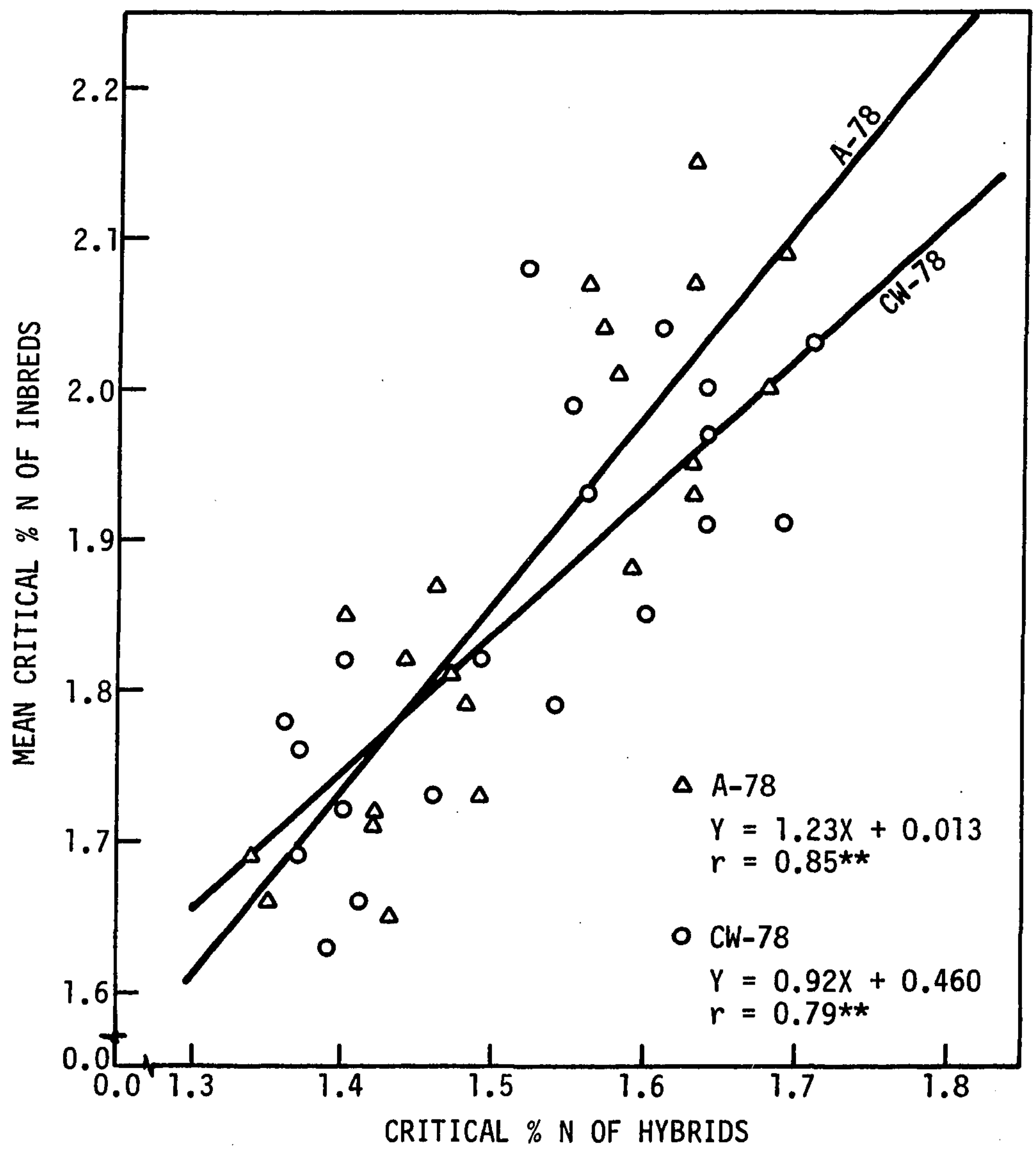

Figure 7. Relationship between the critical %N in the grain of 21 maize single crosses and the mean critical %N of the parental inbreds grown at 2 sites in 1978

Table 20. Critical %N values in the grain for 21 maize pedigree single crosses and for their high and low parental inbreds used in the two 1978 experiments

Hybrid	Critical %N			Critical %N			
				High parent		Low parent	
	A-78	CW-78	Mean	A-78	CW-78	A-78	CW-78
	%			%		%	
B14A x B75	1.63	1.52	1.58	2.28	2.21	2.01[a]	1.95
B14A x B76	1.57	1.55	1.56	2.28	2.21	1.80[a]	1.77
B14A x B77	1.63	1.71	1.67	2.28	2.21	1.86	1.84
B14A x A619	1.58	1.56	1.57	2.28	2.21	1.74	1.65
B14A x Va26	1.68	1.64	1.66	2.28	2.21	1.72[a]	1.72
B14A x N7A	1.56	1.64	1.60	2.28	2.21	1.85	1.78
Mo17 x B75	1.63	1.69	1.66	2.01[a]	1.95	1.89	1.86
Mo17 x B76	1.40	1.40	1.40	1.89	1.86	1.80[a]	1.77
Mo17 x B77	1.59	1.60	1.60	1.89	1.86	1.86	1.84
Mo17 x A619	1.44	1.37	1.41	1.89	1.86	1.74	1.65
Mo17 x Va26	1.47[a]	1.54	1.51	1.89	1.86	1.72[a]	1.72
Mo17 x N7A	1.46	1.49	1.48	1.89	1.86	1.85	1.78
B73 x B75	1.48	1.36	1.42	2.01[a]	1.95	1.57	1.60
B73 x B76	1.34	1.37	1.36	1.80[a]	1.77	1.57	1.60
B73 x B77	1.42	1.40	1.41	1.86	1.84	1.57	1.60
B73 x A619	1.35	1.39	1.37	1.74	1.65	1.57	1.60
B73 x Va26	1.43[a]	1.41	1.42	1.72[a]	1.72	1.57	1.60
B73 x N7A	1.42	1.37	1.40	1.85	1.78	1.57	1.60
B14A x Mo17	1.69	1.61	1.65	2.28	2.21	1.89	1.86
B14A x B73	1.63	1.64	1.64	2.28	2.21	1.57	1.60
Mo17 x B73	1.49	1.46	1.48	1.89	1.86	1.57	1.60

[a]These values were determined by the graphical method.

for %N in maize grain. Thus, a knowledge of the critical %N of parental inbreds will be useful in predicting the critical %N of single crosses from the mean %N for the two parents.

SUMMARY AND CONCLUSIONS

This study was conducted to determine the relationship between the critical %N in the grain of maize parental inbreds and that of their single cross progeny, with the purpose of determining how well the critical %N of the parental inbreds can be used in predicting the critical %N of the progeny. The data were obtained from 3 N fertilizer rate experiments involving 2 sites in Iowa. Twenty-one maize pedigree single crosses were included in each experiment, and the 9 parental inbreds were included in two of the experiments.

A highly significant quadratic response in grain yield to applied N was obtained for the 21 single crosses and the 9 parental inbreds in each of the experiments. The N content in the grain was also significantly increased by the applied N for the single crosses and the parental inbreds.

The differences in the predicted critical %N values in the grain among the 21 single crosses and among the 9 parental inbreds were highly significant. A highly significant correlation was also observed among the site-years in the critical %N values for the 21 single crosses (r= 0.87) and for the 9 parental inbreds (r=0.98).

Hybrids containing B14A as a parental inbred had the highest mean critical %N (1.60), while the hybrids containing Mo17 had an intermediate value (1.49), and the hybrids containing B73 were the lowest (1.38). The parental inbred B14A had the highest mean critical %N (2.25) while the inbred B73 had the lowest (1.59).

The relationship between the critical %N of the single crosses and the mean critical %N of their parental inbreds was highly significant, with r-values of 0.87, 0.85, and 0.79 for the site-years involved.

It was concluded that the critical %N in the grain of maize single crosses can be predicted from a knowledge of the critical %N in the grain of the parental inbreds. This knowledge will be useful in diagnosing N sufficiency, in characterizing maize hybrids for protein feeding value, and in improving maize hybrids for protein content.

PART III. DIFFERENCES IN N-USE EFFICIENCY AMONG MAIZE HYBRIDS

INTRODUCTION

Maize hybrids have been compared for many years for grain yield and other agronomic traits, such as moisture in the grain at maturity, standability, etc. Very little information is available, however, regarding the differences among hybrids as to their efficiency of nutrient use from either the soil or added fertilizers.

Maize requires large amounts of N fertilizer for sustained high yields. In recent years, many producers have applied liberal amounts of N to maize, thinking it was better to have an excess of N than a deficit, in order to be assured that N was not a yield-limiting factor. However, with increased concern about costs, energy consumption, and environmental pollution, efficiency of N use is becoming increasingly important. It would be desirable to know how maize hybrids and inbreds differ in their use of N fertilizer.

Viets and Domingo (1948) and Dumenil (1952) referred to fertilizer N efficiency as the amount of N per unit of yield increase. Pierre et al. (1977a) used this definition in their study, but applied it for the yield increase from the initial (or base) yield level to the maximum yield. They found that the amount of N required per unit of yield increase, referred to as the N requirement index, was affected by the initial relative yield, expressed as a percentage of the maximum yield. This is because yield response curves are usually curvilinear. Therefore, they suggested that for most satisfactory comparisons among experiments or hybrids, the N requirement indexes should be made at the same relative yield with respect to the maximum yield. Capurro and Voss (1981) defined N use efficiency as the increase in yield obtained per unit of N applied over a given range of N rates.

Efficiency of N use has also been based on the percent recovery of applied N by maize plants grown under different conditions. Allison (1966) pointed out that two commonly used methods of determining N recovery are: (a) the percentage of the applied N recovered in vegetative tissue or grain (i.e., the N yield from fertilizer plots minus the N yield from unfertilized plots divided by the amount of N applied times 100), and (b) the percent recovery of added ^{15}N-labeled fertilizer. Nitrogen recovery data for maize grain by the N yield or unlabeled-N method have been reported in a number of investigations. As would be expected, the %N recovery is found to vary greatly with the amount of N applied in relation to the needs of the crop. At levels near maximum yield the %N recovery in the grain have, in general, ranged from about 30 to 45% (Ohlrogge et al., 1943; Viets and Domingo, 1948; Hunter and Yungen, 1955; Galvez et al., 1956; Pierre et al., 1971; Parr, 1973; Jolley and Pierre, 1977).

The objectives of this part of the study were to evaluate the efficiency of different maize single crosses in their use of inherent and applied N, using the following criteria or bases of comparison:

(1) Maximum grain yield and yield responses to N;

(2) N yields and percent N recovery in the grain.

PLANS AND PROCEDURES

The data for this part of the study concerns the first 18 maize pedigree single crosses listed in Table 2 (Part I) that were used in the CW-77, A-78, and CW-78 experiments. These single crosses were selected because they consisted of crosses of 3 well-known inbreds (B14A, Mo17, and B73) of widely different grain N percentages and 6 inbreds (B75, B76, B77, A619, Va26, and N7A) of less variable N percentage in the grain. The 3 inbreds will be referred to as parental inbred testers and the other 6 inbreds, which are common constituents of the single crosses for each tester, will be referred to as parental inbred lines. The data presented consisted of predicted and computed values which provide bases to evaluate the N use efficiency by these 18 single crosses.

The comparison of these 18 single crosses for N use efficiency was made at the maximum grain yield level. This yield level was used to avoid the problem of the various hybrids being at different levels of N sufficiency which could occur if compared at only one level of soil N. At the maximum yield level, the N use efficiency can be studied on a comparable sufficiency basis.

Nitrogen use efficiency by these 18 single crosses was examined by comparing the computed grain yield responses to applied N and the percent N recoveries (as determined from the N yields in the grain). The grain yields (initial and maximum yields), the %N values in the grain (initial and critical %N values), and the N rates required to maximize grain yields were predicted values obtained by the two-step regression method described in Plans and Procedures of Part I.

Description of Terms

Initial yield refers to the predicted grain yield with no fertilizer N applied. Maximum yield was defined in Plans and Procedures (Part I). Gross yield per unit N refers to the maximum grain yield divided by the N rate required to maximize yield. Initial N yield and maximum N yield refer to the computed N yields in the grain (yield times %N) associated with the predicted initial and maximum yields of grain, respectively.

Statistical Analyses

Differences among these computed values for N utilization efficiency by the 18 single crosses were evaluated by use of analysis of variance for each parameter. The analyses of variance were computed for the parameters (a) by assuming a randomized complete block design in which the site-years were considered as replications, and (b) by assuming the variance for each site-year was the same.

RESULTS AND DISCUSSION

This part of the study deals with the evaluation of N use efficiency by 18 maize pedigree single crosses. The basic data are shown in Appendix Tables A15 through A20, and A23. The results of the analyses of variance are shown in Appendix Tables A23 through A25. The predicted and computed values for each parameter have been averaged over 3 site-years (CW-77, A-78, and CW-78) and the discussion will be based on the mean values.

Grain Yields and Yield Responses to N

Initial grain yield

The mean initial yields (with no applied N), the mean maximum yields, and the mean yield responses of 18 pedigree single crosses are shown in Table 21. The mean initial yields were 69.9, 64.7, and 55.9 q/ha for hybrids containing B73, Mo17, and B14A, respectively. The standard error for these values was 2.09 q/ha. Thus, the hybrids containing B73 were more efficient than those of either of the other parental inbred testers in producing the highest yield from soil N alone. The Mo17 hybrids were more efficient than the B14A hybrids in producing grain yield from soil N.

The mean initial yields were 67.3, 66.3, 65.7, 64.1, 60.7, and 57.0 q/ha for the hybrids containing B77, N7A, B75, B76, A619, and Va26, respectively. The standard error for these values was 2.95 q/ha. Among the six parental lines, the mean initial yield of the hybrids containing Va26 as a parental inbred was significantly lower than those of

Table 21. The average initial grain yields, maximum grain yields, and grain yield responses for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental lines	Initial yield (q/ha)				Maximum yield (q/ha)				Yield response (q/ha)			
	Parental testers			Mean	Parental testers			Mean	Parental testers			Mean
	B14A	Mo17	B73		B14A	Mo17	B73		B14A	Mo17	B73	
B75	59.1	64.0	74.0	65.7	112.3	103.7	119.6	111.9	53.2	39.7	45.6	46.2
B76	59.6	65.9	66.7	64.1	100.7	108.4	105.8	105.0	41.1	42.6	39.1	40.9
B77	65.1	64.4	72.4	67.3	105.1	104.5	116.1	108.6	39.9	40.1	43.7	41.3
A619	51.6	62.7	67.7	60.7	99.1	87.3	104.9	97.1	47.5	24.6	37.2	36.4
Va26	42.5	63.5	65.0	57.0	97.3	105.9	102.8	102.0	54.9	42.4	37.8	45.0
N7A	57.5	67.6	73.7	66.3	96.7	104.1	107.7	102.9	39.2	36.5	34.0	36.6
Mean	55.9	64.7	69.9	63.5	101.9	102.3	109.5	104.6	46.0	37.6	39.6	41.1

the hybrids containing B75, B76, B77, and N7A. The mean initial yield for the hybrids containing A619 was intermediate and not significantly different from those of the hybrids containing the other five parental lines. There was no significant interaction between parental testers and parental lines for initial yields.

Maximum grain yield

The mean maximum yields for the hybrids containing the three parental testers, B73, Mo17, and B14A, were 109.5, 102.3, and 101.9 q/ha, respectively. The standard error for these values was 1.89 q/ha. Thus, the mean maximum yields for the hybrids containing B73 were significantly higher than those containing either B14A or Mo17 as the parental testers. There was a significant interaction between the parental testers and parental lines for maximum yields.

Grain yield response

The difference in the mean maximum yields between single crosses containing B14A and B73 were only about half of that between the initial yields of these two groups of single crosses. This is because the mean yield responses of the hybrids containing B14A were significantly higher than those of the other two parental testers, averaging 46.0 q/ha compared to 39.6 and 37.6 q/ha for B73 and Mo17 hybrids, respectively. The standard error for these values was 2.53 q/ha. The comparable percentage increases in yields for B14A, B73, and Mo17 were 82, 58, and 56, respectively.

One of the reasons the yield responses of the B14A hybrids were higher than those of the B73 and Mo17 hybrids was that at the initial yield level the B14A hybrids were at a lower relative percentage of their maximum yield (Appendix Table A22), the values being 54.4 versus 63.3 and 63.4%, respectively. In general, the lower the initial yield is relative to the maximum yield, the higher the yield response to N, because the yield response curve is normally curvilinear (Pierre et al., 1977a). In this study there was a highly significant mean negative correlation coefficient of -0.93 between the initial yields and the yield responses.

The mean yield responses for the hybrids containing B75, Va26, B77, B76, N7A, and A619 were 46.2, 45.0, 41.3, 40.9, 36.6, and 36.4 q/ha, respectively. The standard error for these values was 3.57 q/ha. Thus, the mean yield responses of the hybrids containing B75 or Va26 as parental lines were significantly larger than those of hybrids containing N7A or A619. The mean yield responses of the hybrids containing B77 or B76 were not significantly different from those of any of the other parental lines.

Nitrogen requirement for maximum yield and yield response per unit of N

The mean N rates required for the single crosses to maximize grain yields are shown in the first part of Table 22. There was a significant difference in N requirement when the single crosses were grouped according to the parental tester in the hybrids (i.e., B14A, Mo17, and B73). Hybrids containing B73 as a parental inbred tester required an average of only 169 kg N/ha to maximize grain yields, whereas hybrids containing

Table 22. The average N rates required to maximize yields, grain yield responses per unit N, and gross grain yields per unit N for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental lines	N rate for maximum yield (kgN/ha)				Yield response/ unit N (kg/kgN)				Gross yield/ unit N (kg/kgN)			
	Parental testers			Mean	Parental testers			Mean	Parental testers			Mean
	B14A	Mo17	B73		B14A	Mo17	B73		B14A	Mo17	B73	
B75	182	218	165	188	29.7	18.5	28.1	25.4	62.1	49.5	72.7	61.4
B76	171	161	165	165	24.4	25.2	23.2	24.3	59.9	68.5	64.7	64.4
B77	183	178	168	177	21.5	22.4	25.9	23.2	58.1	59.6	69.8	62.5
A619	165	190	178	178	28.5	13.5	20.1	20.7	60.4	46.3	61.1	55.9
Va26	177	217	160	185	31.1	19.8	23.6	24.9	55.1	48.9	64.2	56.1
N7A	201	181	180	187	19.8	19.7	18.3	19.3	50.4	57.6	60.0	56.0
Mean	180	191	169	180	25.8	19.8	23.2	23.0	57.7	55.1	65.4	59.4

B14A required 180 kg N/ha and those containing Mo17 required 191 kg N/ha. The standard error for these values was 8.0 kg N/ha. Thus, the amounts of N required for maximum yields by the hybrids containing B73 were significantly lower than those for the hybrids containing Mo17, but the other differences were not significant. The single crosses, grouped according to the six parental lines (i.e., B75, B76, B77, A619, Va26, and N7A), were not significantly different in the mean N requirement for maximum yields. The standard error was 11.3 kg N/ha for the differences between the six parental lines.

Yield response per unit N

The mean yield responses per unit N (Table 22) for the hybrids containing B14A, B73, and Mo17 were 25.8, 23.2, and 19.8 kg/kgN, respectively. The standard error was 1.67 kg/kgN. Thus, the mean yield response per unit N for the hybrids containing B14A was significantly greater than for hybrids containing Mo17, but not significantly greater than for the B73 hybrids. The mean yield response per unit N for the B73 hybrids was greater than that for the Mo17 hybrids at the 10 percent but not at the 5 percent level of significance. The reason the mean yield responses per unit of N were slightly higher for B14A than for B73 hybrids, in spite of the fact that the B73 hybrids required less N to produce maximum yields, was that the B14A hybrids responded more to N (Table 21). Since the hybrids containing Mo17 required the most fertilizer N to maximize yields and produced the least response in yield, their mean yield response per unit N was the lowest of the three groups of hybrids.

The mean yield responses per unit of N for the hybrids containing the six parental lines were significantly different at the 10 percent but not at the 5 percent level. The interaction between parental testers and parental lines for this parameter was likewise significant at the 10 percent level.

Nitrogen requirement index

It would have been desirable to compare the single crosses on the basis of their N requirement indexes, considered as the amount of N fertilizer required per unit of grain yield increase from a comparable relative initial yield level to the maximum yield level. However, in this study the lowest relative initial yield that could have been used for the 3 site-years was 80% of the maximum yield, which was too high to permit accurate comparison of the single crosses for N use efficiency.

Gross yield per unit N

A commonly used method of expressing efficiency of fertilizer use is one based on the gross yield per unit N. The last part of Table 22 shows the mean gross yields per unit N. Hybrids containing B73 produced, on the average, 65.4 kg of grain per kg N while those containing B14A produced 57.7 kg/kgN and those containing Mo17 produced 55.1 kg/kgN. The standard error for these values was 2.54 kg/kgN. Thus, hybrids containing B73 were significantly more efficient in producing grain than the hybrids containing either B14A or Mo17 when the total soil and fertilizer N was considered. The mean gross yields per unit N of the hybrids containing the six parental lines were significantly different at the 10 percent level. The interaction between parental testers and parental lines was likewise significant at the 10 percent but not at the 5 percent level.

N Yield and Percent N Recovery

Since the N yields in the grain is a measure of the total protein yield, a comparison of hybrids on this basis should be of interest to livestock producers. Table 23 shows the mean initial N yields and maximum N yields, and Table 24 shows N yield increases and percent N recovery values. The differences between the hybrids, grouped according to the parental testers, were highly significant in all four parameters.

Initial N yield

The mean initial N yields were 60.8, 58.8, and 55.1 kg N/ha for the B73 hybrids, Mo17 hybrids, and B14A hybrids, respectively. The standard error for these values was 1.68 kgN/ha. Thus, at the initial yield level, the hybrids containing B14A produced less grain N yield than hybrids containing either Mo17 or B73. The differences in initial N yields between the hybrids grouped according to the six parental lines was significant at the 10 percent level. The interaction between parental testers and parental lines for initial N yields was not significant.

Table 23. The average initial N yields and maximum N yields in the grain for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental lines	Initial N yield (kgN/ha)				Maximum N yield (kgN/ha)			
	Parental testers			Mean	Parental testers			Mean
	B14A	Mo17	B73		B14A	Mo17	B73	
B75	56.7	63.4	65.2	61.8	150.7	144.1	143.7	146.2
B76	58.3	60.9	57.1	58.8	131.2	127.5	120.4	126.4
B77	60.6	55.3	61.3	59.0	147.9	139.0	136.8	141.2
A619	52.5	55.1	59.2	55.6	133.0	115.4	120.9	123.1
Va26	46.9	58.6	59.9	55.1	134.6	132.2	121.5	129.4
N7A	55.8	59.7	62.1	59.2	128.3	127.2	122.6	126.0
Mean	55.1	58.8	60.8	58.2	137.6	130.9	127.6	132.1

Table 24. The average N yield increases and percent N recoveries in the grain for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental lines	N yield increase (kgN/ha)				%N recovery			
	Parental testers			Mean	Parental testers			Mean
	B14A	Mo17	B73		B14A	Mo17	B73	
B75	94.0	80.7	78.6	84.4	52.3	37.6	48.1	46.0
B76	72.9	66.7	63.3	67.6	43.3	40.5	38.0	40.6
B77	87.3	83.7	75.5	82.2	47.5	47.0	44.9	46.5
A619	80.5	60.3	61.7	67.5	48.7	31.8	34.4	38.3
Va26	87.7	73.6	61.6	74.3	49.5	34.4	38.5	40.8
N7A	72.5	67.5	60.5	66.8	36.9	36.8	33.2	35.6
Mean	82.5	72.1	66.9	73.8	46.3	38.0	39.5	41.3

Maximum N yield

The mean maximum N yields for the hybrids containing the tester inbreds B14A, Mo17, and B73 were 137.6, 130.9, and 127.6 kg N/ha, respectively. The standard error for these values was 2.74 kg N/ha. Thus, the mean N yield of the B14A hybrids was significantly higher than that of either the B73 or the Mo17 hybrids, which were not significantly different. The higher N yield of the B14A hybrids can be attributed to a much larger critical %N in the grain.

The mean maximum N yields for the hybrids containing the parental lines B75, B77, Va26, B76, N7A, and A619 were 146.2, 141.2, 129.4, 126.4, 126.0, and 123.1 kg N/ha, respectively; and the standard error was 3.88 kg N/ha. Consequently, the mean maximum N yields of hybrids containing B75 or B77 were significantly higher than those of the hybrids containing the other four parental lines, but these four were not significantly different from each other. The interaction between parental testers and lines was not significant.

N yield increase

The mean increases in N yields for the hybrids containing B14A, Mo17, and B73 were 82.5, 72.1, and 66.9 kg N/ha, respectively. The standard error for these values was 3.09 kg N/ha. Thus, the hybrids containing B14A recovered more fertilizer N in the grain than did the hybrids containing either Mo17 or B73. Based on the N yields at the initial yield level the mean increases in N yield for the B14A, Mo17, and B73 hybrids were 150, 130, and 110 percent, respectively.

The mean N yield increases for the hybrids containing B75, B77, Va26, B76, A619, and N7A were 84.4, 82.2, 74.3, 67.6, 67.5, and 66.8, respectively, with a standard error of 4.37 kg N/ha. The B75 and B77 hybrids recovered significantly more fertilizer N in the grain than did the hybrids containing either B76, A619, or N7A. The fertilizer N recovered by Va26 hybrids was not significantly different from that recovered by the other five parental lines. The interaction between parental testers and lines was not significant.

Percent N recovery

The mean percent N recovery in the grain of the fertilizer N required for maximum yields for the hybrids containing B14A, B73, and Mo17 were 46.3, 39.5, and 38.0, respectively (Table 24). The standard error for these values was 1.94 percent. The differences in percent N recovery between the B14A hybrids and those from B73 and Mo17 hybrids were statistically significant. Hybrids of Mo17 and B73, however, did not differ significantly from each other. Thus, as was observed earlier in regard to yield response, hybrids containing B14A were found to be significantly more efficient in utilizing fertilizer N for maximum N yields and in percent of fertilizer N recovered in the grain.

For the hybrids containing B77, B75, Va26, B76, A619, and N7A, the mean percent N recovery values were 46.5, 46.0, 40.8, 40.6, 38.3, and 35.6 percent, respectively; and the standard error was 2.74 percent. Hybrids from B75 and B77 were higher in percent N recovery than all the other hybrids, but were significantly higher only for hybrids from

A619 and N7A. The interaction between parental testers and parental testers was not significant.

SUMMARY AND CONCLUSIONS

The objective of this study was to evaluate the efficiency of different maize single crosses in their use of indigenous and applied N. Predicted and computed data for 18 pedigree single crosses grown in 3 experiments were used for the comparative study. The hybrids included all possible crosses of 3 parental inbred testers and 6 parental inbred lines. The primary measures of efficiency used included: (1) maximum grain yield and yield response to applied N; (2) N yield and percent N recovery in the grain; and (3) efficiency ratios.

Maximum Grain Yield and Yield Response to N

Hybrids containing B73 as a parental inbred tester produced significantly greater initial (with no applied N) and maximum grain yields than hybrids containing either Mo17 or B14A as a parental inbred tester. However, because of a significantly greater yield response to applied N hybrids containing B14A had a slight advantage over the B73 hybrids and a significant advantage over the Mo17 hybrids in yield response per unit of N to attain maximum yield. Hybrids grouped according to the parental inbred lines showed very little differences in grain yields and yield responses per unit of N.

N Yield and Percent N Recovery

The initial N yields in the grain were slightly higher for hybrids containing B73 as a parental inbred tester than for hybrids containing Mo17 and significantly higher than hybrids containing B14A as a parental inbred tester. This was largely due to the greater initial grain yields of the hybrids containing B73 than the other 2 groups of hybrids. Because of a much higher critical %N in the grain, the hybrids containing B14A as a parental inbred tester had significantly greater maximum N yields, N yield increases, and percent N recoveries of applied N in the grain than hybrids containing either Mo17 or B73. Hybrids containing either B75 or B77 as a parental inbred line also had a higher critical %N in the grain and consequently had higher maximum N yields, N yield increases, and percent N recoveries than the hybrids containing any of the other parental inbred lines.

Conclusions

The results obtained in this investigation show that maize single crosses may vary considerably in efficiency of N use, not only from the standpoint of grain yield and yield response to N, but also from the standpoint of N yield and the recovery of applied N in the grain as protein. Some hybrids may be relatively high in grain yields at both low and optimum N levels (levels necessary to maximize yields) and relatively low in maximum N yields and fertilizer N recovery in grain as protein. This was true for single crosses with B73 as a parental inbred. On the other hand, some single crosses may be relatively low in maximum grain yields and high in maximum N yields and fertilizer N recovery in the grain as protein. This was true for single crosses with B14A as a parental inbred. This means that the basis of comparing single-cross hybrids for N use efficiency needs to be determined in relation to the objective sought.

The high and generally increasing costs of energy, and consequently of fertilizer N, emphasizes the need of utilizing N efficiently, and of determining the extent to which different maize hybrids differ in efficiency of N use. It also emphasizes the desirability of recognizing efficiency of N use in maize breeding programs.

GENERAL SUMMARY AND CONCLUSIONS

Critical %N is defined as the N concentration associated with maximum yield with respect to N. The major objectives of the research were: (1) to determine the extent to which maize single crosses differ in their critical %N; (2) to determine the constancy of these values in different crop seasons; (3) to determine the relationship between the critical %N of single crosses and the mean critical %N of their parental lines; and (4) to evaluate the efficiency of different single crosses with respect to N use. Data were from 4 site-years at 2 research centers in Iowa. The 1976 experiment and one of the 1978 experiments were located on separate sites at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa. These sites were referred to as A-76 and A-78 in the presentation of results. The 1977 and the other 1978 experiment were located on the same site at the Clarion-Webster Research Center near Kanawha, Iowa (CW-77 and CW-78). The maximum yields and critical %N values were predicted from the separate regressions of yield and of %N on the quadratic functions of N fertilizer rates.

Differences in Critical %N

A highly significant difference in critical %N in the grain was observed for the maize hybrids and inbreds used in this study. The ranges in critical %N in the grain among commercial hybrids and pedigree single crosses were quite similar. The 14 commercial hybrids ranged in critical %N from 1.42 to 1.73 %N (A-76), whereas the 12 pedigree single crosses ranged from 1.39 to 1.73 %N (A-76) and 1.35 to 1.71 %N (CW-77). The critical %N in the grain for the 21 pedigree single crosses ranged from 1.25 to 1.66 %N (CW-77), 1.34 to 1.69 %N (A-78), and 1.36 to 1.71 %N (CW-78). The critical %N in the grain for the 9 maize parental inbreds ranged from 1.59 to 2.25 %N. Since these ranges in critical %N occur among hybrids and inbreds, it is obvious that they must be categorized with respect to this trait if it is to be useful in diagnosing N sufficiency, in characterizing protein feeding value and improving maize for protein content.

Site-year Differences

Although the critical %N in the grain of the 12 pedigree single crosses for 2 site-years (1.53 %N in A-76 and 1.49 %N in CW-77) and of the 21 pedigree single crosses for 3 site-years (1.48 %N in CW-77, 1.51 %N in A-78, and 1.52 %N in CW-78) were significantly different, the differences due to site-years were small compared to the differences due to hybrids. The critical %N values of the hybrids for the different site-years were highly correlated. The correlation coefficients between the 2 site-years for 12 single crosses was 0.90**; and those among 3 site-years for 21 single crosses ranged from 0.83** to 0.90** and averaged 0.87**. The critical %N values for the 9 parental inbreds for the 2 site-years in 1978 were highly correlated ($r = 0.98$*).

No evidence was obtained in these experiments that differences in soil P availability or of slight to moderate differences in moisture stress were responsible for the differences in critical %N in different site-years.

Associated P Percentages

The hybrids differed significantly in the predicted P percentages at maximum yields with respect to N in the two experiments where this parameter was measured. Highly significant correlations were obtained between critical %N and the associated P percentage, the r-values being 0.76 for A-76 and 0.83 for CW-77. From a livestock feeding viewpoint, it means that hybrids that are high in optimum protein percentages also tend to be high in P percentage.

Relationship between Critical %N of Single Crosses and their Parental Inbreds

As indicated earlier, a wide range in critical %N was observed among the hybrids and inbreds tested. The relationship between the critical %N of these single crosses and the mean critical %N of their parental inbreds was highly significant, with r-values of 0.87, 0.85, 0.79 for the site-years involved. It was concluded that a knowledge of the critical %N in the grain of the parental inbreds can be useful for the prediction of the critical %N in the grain of maize single crosses.

Efficiency of N Use

Hybrids containing B73 as a parental inbred tester produced the most grain with only indigenous N as well as with sufficient applied N to maximize yields. However, hybrids containing B14A as a parental inbred tester were at least as efficient in producing grain yield response per unit of applied N as were the B73 containing hybrids. Hybrids containing Mo17 as a parental inbred tester were of intermediate rank in both yield and efficiency. With no applied N, hybrids containing B73 as a parental inbred tester contained more total N in the grain than hybrids containing B14A, and about the same as the hybrids containing Mo17 as a parental inbred tester. However, at the maximum yield level with respect to N, hybrids containing B14A as a parental inbred tester contained more total N in the grain than the hybrids containing the other inbred testers. Hybrids containing B14A as a parental inbred tester were the most efficient of the 3 groups of hybrids in their percent N recovery in the grain of the N applied to maximize yields.

The high and generally increasing costs of energy, and consequently of fertilizer N, emphasizes the need of utilizing N efficiently, and of determining the extent to which different maize hybrids differ in efficiency of N use. It also emphasizes the desirability of recognizing efficiency of N use in maize breeding programs.

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APPENDIX

Table A1. Grain yields and regression data for the 26 maize hybrids used in the A-76 experiment

Hybrid	Grain yields (q/ha)					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	67	134	201	268				
A631 x A239	46.4	72.3	78.6	76.8	76.9	48.6	3.51	-9.44	.76
A632 x Oh551	46.6	69.9	69.7	75.5	72.2	48.6	2.85	-7.45	.48
B14A x B77	35.6	72.4	82.8	85.9	79.3	37.6	5.50	-14.87	.76
B37 x B70	71.6	86.6	89.8	93.4	95.6	72.9	1.88	-3.96	.53
B70 x B14A	63.5	77.4	86.7	90.9	84.1	63.0	2.78	-7.31	.51
B70 x B73	63.7	87.6	88.4	95.1	88.4	65.3	3.19	-8.72	.57
B73 x A619	57.7	83.1	83.3	84.1	81.2	60.3	3.09	-8.85	.52
B75 x A632	52.4	84.4	82.3	86.2	87.4	56.3	3.43	-8.77	.65
B75 x B37	58.1	82.7	84.5	84.7	84.9	60.7	2.96	-7.94	.36
B77 x B37	65.0	79.7	87.7	95.3	92.5	64.8	2.56	-5.60	.64
N7A x Mo17	68.9	87.7	77.8	95.1	81.3	70.3	2.09	-5.98	.32
Oh545 x A632	58.9	76.1	65.2	77.6	62.0	60.4	1.91	-6.68	.19
Ames Best SX37	56.0	67.4	63.4	71.1	66.9	57.1	1.20	-3.07	.19
DeKalb XL43	60.4	74.6	78.0	79.7	67.7	60.4	2.59	-8.53	.56
DeKalb XL64	63.7	77.0	78.3	86.8	77.9	63.8	2.14	-5.85	.47
DeKalb XL75	69.3	93.7	84.2	83.0	88.5	74.0	1.66	-4.66	.19
Funks G4321A	46.9	74.3	67.8	77.5	68.1	49.6	3.12	-9.08	.54
Iowa State M116A	53.9	84.9	72.3	80.7	71.7	58.0	2.97	-9.32	.35
NK PX50A	53.0	70.8	66.8	72.6	69.4	55.0	1.88	-5.07	.35
NK PX74	65.3	93.4	93.3	99.2	88.2	67.2	3.84	-11.43	.64
Pioneer 3780	52.0	76.3	75.1	77.2	78.4	54.9	2.62	-6.77	.66
Trojan TXS94	50.0	68.7	71.7	68.1	69.0	52.0	2.35	-6.66	.62
Trojan TXS99	51.1	64.6	71.4	65.9	74.1	52.7	1.68	-3.61	.53
Trojan TXS108A	59.2	76.6	85.6	85.9	78.3	59.3	3.20	-9.27	.35
Trojan TXS113	52.9	72.2	86.7	90.3	84.5	52.3	3.81	-9.66	.81
Trojan TXS119	57.6	81.2	82.7	90.6	89.0	59.5	2.93	-6.92	.49
Mean	56.9	78.3	79.3	83.4	79.1	58.6	2.76	-7.52	.36

[a]Values for b_ℓ were multiplied by 10^1. The standard error for these linear coefficients by hybrid is 0.62 and 0.12 for the mean of hybrids. Values for b_q were multiplied by 10^4. The standard error for these quadratic coefficients by hybrid is 2.21 and 0.43 for the mean of hybrids.

Table A2. Nitrogen percentages in the grain and regression data for the 26 maize hybrids used in the A-76 experiment

Hybrid	Nitrogen percentage					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	67	134	201	268				
A631 x A239	1.14	1.27	1.34	1.41	1.46	1.14	1.92	-2.83	.81
A632 x Oh551	1.35	1.50	1.65	1.76	1.80	1.34	2.84	-4.11	.91
B14A x B77	1.34	1.46	1.59	1.68	1.82	1.34	1.76	-0.11	.78
B37 x B70	1.17	1.23	1.38	1.45	1.50	1.15	1.73	-1.52	.77
B70 x B14A	1.28	1.45	1.57	1.64	1.80	1.29	2.10	-0.99	.85
B70 x B73	1.11	1.28	1.42	1.46	1.54	1.12	2.62	-3.96	.88
B73 x A619	1.05	1.21	1.36	1.38	1.53	1.06	2.27	-2.23	.87
B75 x A632	1.25	1.39	1.61	1.63	1.72	1.24	3.04	-4.74	.81
B75 x B37	1.22	1.37	1.42	1.52	1.60	1.23	1.75	-1.42	.82
B77 x B37	1.16	1.33	1.40	1.52	1.59	1.17	2.18	-2.31	.86
N7A x Mo17	1.15	1.24	1.39	1.45	1.58	1.14	1.66	-0.32	.71
Oh545 x A632	1.20	1.29	1.50	1.59	1.70	1.18	2.28	-1.25	.78
Ames Best SX37	1.20	1.30	1.53	1.61	1.67	1.18	2.90	-3.84	.74
DeKalb XL43	1.13	1.27	1.46	1.51	1.57	1.12	3.00	-4.97	.86
DeKalb XL64	1.16	1.30	1.45	1.46	1.55	1.16	2.36	-3.57	.87
DeKalb XL75	1.23	1.30	1.39	1.46	1.61	1.23	0.80	2.07	.69
Funks G4321A	1.16	1.29	1.54	1.55	1.70	1.15	2.83	-3.11	.87
Iowa State M116A	1.18	1.31	1.52	1.50	1.64	1.18	2.45	-2.97	.72
NK PX50A	1.15	1.34	1.53	1.61	1.66	1.15	3.55	-6.13	.91
NK PX74	1.11	1.24	1.40	1.43	1.55	1.11	2.20	-2.34	.83
Pioneer 3780	1.12	1.40	1.52	1.50	1.64	1.15	3.43	-6.44	.82
Trojan TXS94	1.18	1.33	1.47	1.52	1.53	1.18	2.91	-5.95	.83
Trojan TXS99	1.36	1.54	1.67	1.71	1.73	1.36	3.06	-6.33	.81
Trojan TXS108A	1.24	1.38	1.61	1.61	1.79	1.24	2.59	-2.29	.77
Trojan TXS113	1.10	1.28	1.38	1.42	1.52	1.12	2.26	-3.05	.81
Trojan TXS119	1.16	1.36	1.52	1.60	1.68	1.16	3.22	-4.88	.83
Mean	1.19	1.33	1.48	1.54	1.63	1.19	2.45	-3.06	.64

[a]Values for b_ℓ were multiplied by 10^3. The standard error for these linear coefficients by hybrids is 0.48 and 0.09 for the mean of hybrids. Values for b_q were multiplied by 10^6. The standard error for these quadratic coefficients by hybrid is 1.71 and 0.34 for the mean of hybrids.

Table A3. Phosphorus percentages in the grain and regression data for the 26 maize hybrids used in the A-76 experiment

Hybrid	Phosphorus percentage					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	67	134	201	268				
A631 x A239	.243	.222	.230	.225	.235	.241	-2.28	7.67	.08
A632 x Oh551	.320	.279	.291	.281	.287	.315	-4.10	11.72	.12
B14A x B77	.286	.253	.260	.249	.259	.283	-3.71	10.55	.14
B37 x B70	.237	.206	.222	.223	.228	.231	-2.36	8.78	.06
B70 x B14A	.274	.254	.253	.253	.269	.273	-3.13	11.05	.09
B70 x B73	.253	.227	.234	.218	.235	.251	-3.27	9.66	.14
B73 x A619	.248	.214	.232	.223	.232	.243	-2.92	9.51	.10
B75 x A632	.294	.254	.250	.243	.263	.292	-6.09	18.63	.26
B75 x B37	.255	.221	.224	.231	.237	.251	-3.97	13.26	.24
B77 x B37	.249	.222	.223	.234	.227	.246	-3.18	9.47	.10
N7A x Mo17	.228	.210	.228	.219	.244	.226	-1.90	9.35	.10
Oh545 x A632	.270	.255	.254	.250	.269	.270	-2.92	10.52	.06
Ames Best SX37	.267	.238	.270	.253	.255	.261	-0.74	2.24	.01
DeKalb XL43	.240	.225	.251	.250	.262	.236	-0.17	4.39	.13
DeKalb XL64	.238	.221	.242	.243	.249	.233	-0.44	4.07	.08
DeKalb XL75	.235	.211	.201	.209	.202	.233	-3.28	8.43	.19
Funks G4321A	.274	.225	.241	.235	.261	.269	-5.67	20.24	.28
Iowa State M116A	.255	.222	.241	.235	.236	.249	-2.20	6.76	.07
NK PX50A	.252	.231	.245	.243	.251	.248	-1.56	6.35	.04
NK PX74	.232	.208	.214	.221	.226	.228	-2.49	9.32	.09
Pioneer 3780	.271	.243	.239	.239	.241	.269	-3.72	10.26	.23
Trojan TXS94	.272	.228	.241	.238	.236	.265	-3.75	10.55	.23
Trojan TXS99	.290	.277	.295	.275	.297	.289	-1.13	4.89	.02
Trojan TXS108A	.262	.234	.259	.245	.263	.258	-2.09	8.46	.04
Trojan TXS113	.260	.221	.220	.212	.226	.257	-5.37	15.76	.31
Trojan TXS119	.247	.207	.223	.212	.231	.242	-4.24	14.30	.21
Mean	.260	.231	.242	.236	.247	.256	-2.95	9.85	.06

[a]Values for b_ℓ were multiplied by 10^4. The standard error for these linear coefficients by hybrids is 1.10 and 0.22 for the mean of hybrids. Values for b_q were multiplied by 10^7. The standard error for these quadratic coefficients by hybrid is 3.90 and 0.76 for the mean of hybrids.

Table A4. Grain yields and regression data for the 30 maize pedigree single crosses used in the CW-77 experiment

Hybrids	Grain yields (q/ha) N applied (kg/ha) 0	56	112	168	224	Regression data[a] Intercept	b_ℓ	b_q	R^2
B14A x B75	73.2	96.8	97.3	113.0	109.9	74.6	3.54	- 8.67	.51
B14A x B76	73.1	94.2	103.1	104.5	96.9	73.5	4.34	-14.73	.48
B14A x B77	76.1	101.8	106.3	111.3	108.3	77.8	4.23	-12.98	.54
B14A x A619	66.7	87.3	88.4	98.8	84.7	67.1	3.91	-13.67	.35
B14A x Va26	49.1	80.0	83.5	91.7	84.7	51.0	5.10	-16.16	.59
B14A x N7a	68.2	93.2	101.3	95.1	96.8	70.4	4.16	-13.84	.66
Mo17 x B75	81.0	94.1	92.5	107.0	104.0	81.7	1.87	- 3.65	.51
Mo17 x B76	83.3	103.9	113.0	103.7	102.4	84.8	3.85	-14.14	.38
Mo17 x B77	78.6	95.6	111.1	108.6	104.0	78.0	4.27	-13.94	.63
Mo17 x A619	71.7	75.6	84.5	85.6	86.0	70.9	1.44	- 3.35	.27
Mo17 x Va26	71.3	97.3	100.7	97.1	116.3	75.6	2.66	- 4.72	.47
Mo17 x N7a	83.5	92.8	105.5	108.2	104.9	82.3	2.84	- 8.05	.58
B73 x B75	94.9	116.0	119.3	128.1	122.3	95.8	3.66	-11.00	.60
B73 x B76	80.5	104.4	105.4	111.2	106.1	82.3	3.75	-12.09	.47
B73 x B77	87.7	112.3	122.6	131.7	119.4	87.4	5.31	-17.10	.59
B73 x A619	90.3	100.4	105.1	106.6	98.7	90.0	2.41	- 8.93	.23
B73 x Va26	96.5	108.9	117.4	112.9	114.4	97.1	2.48	- 7.92	.44
B73 x N7a	85.7	106.2	106.4	113.4	113.4	87.6	2.87	- 7.80	.57
B14A x Mo17	76.7	111.7	110.1	116.7	116.6	80.6	4.67	-14.09	.54
B14A x B73	72.2	89.7	104.7	100.0	99.8	72.4	3.97	-12.51	.63
Mo17 x B73	93.8	119.7	115.4	125.5	126.7	96.9	3.07	- 7.98	.59
A631 x A239	67.6	92.2	89.6	90.1	91.1	70.9	3.04	-10.00	.38
A632 x Oh551	79.2	91.4	100.0	100.8	94.7	78.8	2.98	-10.06	.50
B37 x B70	73.7	97.4	112.8	106.5	109.8	74.8	4.64	-14.22	.57
B70 x B14A	79.4	101.1	105.6	119.8	116.9	80.2	3.68	- 8.95	.74
B70 x B73	90.4	111.9	114.5	123.7	124.7	92.0	3.19	- 7.83	.76
B75 x A632	83.2	96.6	105.9	99.3	103.1	84.1	2.54	- 7.96	.37
B75 x B37	68.0	91.7	99.1	105.8	102.4	68.9	4.28	-12.49	.56
B77 x B37	75.9	104.5	110.6	113.4	97.7	76.8	5.62	-20.89	.49
Oh545 x A632	80.3	99.8	103.4	105.3	78.9	79.6	4.82	-21.31	.57
Mean	78.4	98.9	104.5	107.8	104.5	79.5	3.64	-11.37	.34

[a]Values for b_ℓ were multipled by 10^1. The standard error for these linear coefficients by hybrid is 0.92 and 0.17 for the mean of hybrids. Values for b_q were multiplied by 10^4. The standard error for these quadratic coefficients by hybrid is 3.92 and 0.72 for the mean of hybrids.

Table A5. Nitrogen percentages in the grain and regression data for the 30 maize pedigree single crosses used in the CW-77 experiment

Hybrids	Nitrogen percentage					Regression data[a]			
	N applied (kg/ha)					Intercept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A x B75	1.18	1.32	1.51	1.55	1.64	1.17	3.32	-5.64	.89
B14A x B76	1.11	1.32	1.43	1.53	1.58	1.12	3.73	-7.48	.79
B14A x B77	1.14	1.37	1.57	1.66	1.70	1.13	5.03	-11.16	.89
B14A x A619	1.21	1.43	1.56	1.66	1.71	1.22	3.99	-8.16	.85
B14A x Va26	1.41	1.39	1.53	1.62	1.72	1.39	0.50	4.52	.68
B14A x N7A	1.06	1.33	1.47	1.52	1.57	1.16	3.54	-7.66	.92
Mo17 x B75	1.17	1.40	1.57	1.59	1.65	1.18	4.48	-10.94	.86
Mo17 x B76	1.07	1.22	1.36	1.39	1.44	1.07	3.12	-6.78	.79
Mo17 x B77	1.06	1.24	1.48	1.57	1.62	1.04	4.65	-9.21	.93
Mo17 x A619	1.10	1.31	1.39	1.46	1.48	1.11	3.73	-9.37	.84
Mo17 x Va26	1.08	1.27	1.35	1.44	1.43	1.09	3.51	-8.84	.90
Mo17 x N7A	1.03	1.20	1.34	1.38	1.37	1.02	3.98	-10.87	.87
B73 x B75	1.02	1.26	1.35	1.41	1.44	1.03	4.04	-10.05	.92
B73 x B76	0.99	1.18	1.28	1.34	1.34	1.00	3.62	-9.39	.90
B73 x B77	1.02	1.13	1.32	1.38	1.43	1.00	3.30	-6.25	.89
B73 x A619	1.05	1.21	1.35	1.36	1.37	1.05	3.56	-9.64	.89
B73 x Va26	1.05	1.21	1.29	1.40	1.37	1.05	3.22	-7.73	.86
B73 x N7A	0.97	1.14	1.22	1.24	1.25	0.98	3.06	-8.53	.87
B14A x Mo17	1.14	1.39	1.56	1.66	1.65	1.13	5.35	-13.51	.90
B14A x B73	1.16	1.33	1.51	1.55	1.54	1.15	4.43	-11.94	.83
Mo17 x B73	1.01	1.23	1.29	1.34	1.40	1.03	3.20	-7.14	.88
A631 x A239	1.13	1.28	1.38	1.40	1.39	1.13	3.26	-9.48	.79
A632 x Oh551	1.23	1.47	1.60	1.67	1.66	1.23	4.77	-12.82	.91
B37 x B70	1.06	1.23	1.37	1.38	1.49	1.07	3.08	-5.80	.80
B70 x B14A	1.16	1.39	1.63	1.68	1.70	1.15	5.62	-14.12	.89
B70 x B73	1.06	1.25	1.34	1.46	1.47	1.06	3.61	-7.91	.85
B75 x A632	1.14	1.33	1.50	1.47	1.55	1.15	3.87	-9.64	.83
B75 x B37	1.12	1.26	1.42	1.48	1.44	1.11	3.83	-10.19	.84
B77 x B37	1.05	1.24	1.43	1.48	1.51	1.05	4.39	-10.32	.86
Oh545 x A632	1.00	1.25	1.36	1.36	1.44	1.02	3.96	-9.75	.88
Mean	1.10	1.29	1.42	1.48	1.51	1.10	3.79	-8.86	.61

[a]Values for b_ℓ were multiplied by 10^3. The standard error for these linear coefficients by hybrids is 0.49 and 0.09 for the mean of hybrids. Values for b_q were multiplied by 10^6. The standard error for these quadratic coefficients by hybrid is 2.09 and 0.38 for the mean of hybrids.

Table A6. Phosphorus percentages in the grain and regression data for the 30 maize pedigree single crosses used in the CW-77 experiment

Hybrids			Phosphorus percentage					Regression data[a]			
			N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
			0	56	112	168	224				
B14A	x	B75	.336	.325	.333	.327	.341	.335	-1.64	8.25	.08
B14A	x	B76	.345	.350	.343	.351	.355	.347	-0.31	2.89	.04
B14A	x	B77	.343	.359	.363	.349	.335	.344	3.49	-17.76	.29
B14A	x	A619	.337	.346	.341	.336	.342	.340	0.30	-1.32	.00
B14A	x	Va26	.377	.363	.344	.355	.346	.377	-3.35	9.28	.36
B14A	x	N7A	.332	.342	.340	.343	.338	.333	1.49	-5.75	.10
Mo17	x	B75	.315	.317	.317	.310	.327	.317	-0.84	5.07	.09
Mo17	x	B76	.302	.295	.304	.310	.309	.300	0.02	2.27	.14
Mo17	x	B77	.299	.302	.312	.303	.304	.299	1.37	-5.30	.10
Mo17	x	A619	.284	.290	.294	.294	.298	.285	0.92	-1.71	.11
Mo17	x	Va26	.305	.301	.294	.290	.292	.306	-1.52	3.80	.15
Mo17	x	N7A	.286	.293	.303	.306	.312	.286	1.57	-1.93	.32
B73	x	B75	.304	.304	.307	.308	.306	.303	0.54	-1.84	.02
B73	x	B76	.300	.315	.305	.316	.306	.301	1.67	-6.30	.16
B73	x	B77	.287	.298	.300	.292	.288	.288	1.97	-9.14	.13
B73	x	A619	.293	.296	.290	.286	.298	.295	-1.00	4.39	.04
B73	x	Va26	.306	.310	.300	.310	.303	.306	-0.01	-0.41	.00
B73	x	N7A	.290	.297	.293	.308	.294	.290	1.39	-4.71	.12
B14A	x	Mo17	.346	.353	.362	.353	.351	.346	1.98	-8.09	.12
B14A	x	B73	.347	.359	.363	.348	.342	.348	2.45	-12.62	.44
Mo17	x	B73	.294	.305	.306	.302	.304	.295	1.60	-5.80	.13
A631	x	A239	.304	.299	.309	.307	.309	.302	0.22	0.57	.06
A632	x	Oh551	.367	.378	.377	.351	.363	.371	0.54	-5.27	.13
B37	x	B70	.327	.319	.325	.320	.329	.326	-1.09	5.25	.04
B70	x	B14A	.350	.350	.357	.347	.352	.350	0.34	-1.46	.00
B70	x	B73	.310	.314	.320	.322	.318	.309	1.47	-4.68	.14
B75	x	A632	.337	.324	.331	.317	.322	.336	-1.44	3.41	.09
B75	x	B37	.322	.308	.315	.323	.318	.318	-0.79	4.09	.02
B77	x	B37	.308	.305	.317	.312	.314	.306	0.79	-1.98	.05
Oh545	x	A632	.336	.335	.312	.293	.309	.342	-3.66	8.57	.46
Mean			.320	.322	.322	.320	.321	.320	0.28	-1.27	.00

[a]Values for b_ℓ were multiplied by 10^4. The standard error for these linear coefficients by hybrids is 1.01 and 0.18 for the mean of hybrids. Values for b_q were multiplied by 10^7. The standard error for these quadratic coefficients by hybrid is 4.29 and 0.78 for the mean of hybrids.

Table A7. Grain yields and regression data for the 21 maize pedigree single crosses used in the A-78 experiment

Hybrid	Grain yields (q/ha)					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A x B75	72.7	96.0	109.0	117.8	108.9	72.3	5.17	-15.59	.78
B14A x B76	76.6	94.0	91.1	106.2	100.0	77.6	2.55	- 6.64	.40
B14A x B77	78.9	93.8	105.7	101.1	106.9	79.0	3.01	- 8.26	.47
B14A x A619	64.1	91.5	99.0	99.6	105.6	66.7	4.15	-11.26	.67
B14A x Va26	53.8	87.6	99.0	98.3	110.2	57.1	5.06	-12.74	.71
B14A x N7A	68.3	80.2	91.4	91.4	97.5	68.6	2.40	- 5.16	.67
Mo17 x B75	68.1	89.4	97.8	97.0	95.7	69.3	3.89	-12.37	.54
Mo17 x B76	83.7	91.2	101.4	102.1	98.2	82.7	2.36	- 7.34	.49
Mo17 x B77	71.9	90.1	100.3	106.2	104.8	72.1	3.67	- 9.86	.71
Mo17 x A619	70.5	81.8	83.9	91.2	88.0	70.8	2.01	- 5.42	.33
Mo17 x Va26	71.4	80.7	86.9	97.9	102.2	71.4	1.67	- 1.18	.69
Mo17 x N7A	78.8	96.2	100.3	99.0	102.7	80.6	2.58	- 7.50	.42
B73 x B75	85.7	107.4	109.6	118.0	113.9	87.1	3.50	-10.30	.50
B73 x B76	74.8	101.8	101.8	96.8	103.8	78.7	3.24	-10.22	.52
B73 x B77	80.0	97.2	116.5	108.4	112.1	80.0	4.12	-12.35	.59
B73 x A619	74.0	94.5	102.0	101.8	109.2	75.9	3.12	- 7.73	.49
B73 x Va26	66.5	74.7	88.2	101.4	100.6	64.7	2.63	- 4.18	.68
B73 x N7A	82.2	98.5	96.9	98.4	99.7	84.3	1.99	- 6.12	.36
B14A x Mo17	79.0	88.1	100.5	113.1	116.3	77.8	2.38	- 2.66	.63
B14A x B73	58.3	74.9	73.6	87.4	90.2	59.8	2.00	- 2.84	.48
Mo17 x B73	84.8	102.3	102.0	112.8	112.8	86.2	2.40	- 5.40	.56
Mean	73.5	91.0	97.9	102.2	103.8	74.4	3.04	- 7.86	.43

[a]Values for b_ℓ were multiplied by 10^1. The standard error for these linear coefficients by hybrid is 0.80 and 0.17 for the mean of hybrids. Values for b_q were multiplied by 10^4. The standard error for these quadratic coefficients by hybrid is 3.43 and 0.75 for the mean of hybrids.

Table A8. Nitrogen percentages in the grain and regression data for the 21 maize pedigree single crosses used in the A-78 experiment

Hybrid	Nitrogen percentage					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A x B75	1.16	1.41	1.54	1.62	1.65	1.17	4.58	-10.96	.88
B14A x B76	1.20	1.34	1.50	1.56	1.58	1.19	3.56	-8.12	.91
B14A x B77	1.15	1.30	1.50	1.61	1.69	1.13	3.76	-5.68	.91
B14A x A619	1.21	1.33	1.49	1.58	1.61	1.20	3.17	-5.82	.79
B14A x Va26	1.30	1.39	1.58	1.61	1.71	1.29	2.56	-3.11	.77
B14A x N7A	1.17	1.33	1.47	1.50	1.56	1.17	3.24	-6.82	.91
Mo17 x B75	1.25	1.47	1.60	1.58	1.69	1.26	3.67	-8.48	.73
Mo17 x B76	1.12	1.28	1.34	1.41	1.43	1.13	2.64	-5.84	.80
Mo17 x B77	1.09	1.32	1.47	1.57	1.61	1.09	4.56	-10.03	.94
Mo17 x A619	1.03	1.25	1.38	1.39	1.45	1.04	3.95	-9.80	.92
Mo17 x Va26	1.15	1.27	1.37	1.46	1.47	1.15	2.57	-4.91	.86
Mo17 x N7A	1.09	1.25	1.38	1.47	1.48	1.09	3.53	-7.93	.88
B73 x B75	1.11	1.29	1.43	1.48	1.49	1.11	3.77	-9.32	.85
B73 x B76	1.01	1.22	1.27	1.34	1.34	1.02	3.40	-8.89	.90
B73 x B77	1.09	1.21	1.35	1.41	1.49	1.08	2.70	-4.12	.72
B73 x A619	1.05	1.16	1.26	1.30	1.37	1.06	2.12	-3.34	.84
B73 x Va26	1.19	1.26	1.36	1.43	1.45	1.18	1.86	-2.68	.75
B73 x N7A	1.06	1.26	1.36	1.43	1.43	1.07	3.70	-9.19	.90
B14A x Mo17	1.23	1.43	1.58	1.72	1.69	1.22	4.61	-10.91	.83
B14A x B73	1.20	1.36	1.55	1.60	1.63	1.19	4.07	-9.32	.78
Mo17 x B73	1.14	1.26	1.38	1.46	1.48	1.13	2.88	-5.75	.81
Mean	1.14	1.30	1.44	1.50	1.54	1.14	3.38	-7.19	.63

[a]Values for b_ℓ were multiplied by 10^3. The standard error for these linear coefficients by hybrids is 0.50 and 0.11 for the mean of hybrids. Values for b_q were multiplied by 10^6. The standard error for these quadratic coefficients by hybrid is 2.13 and 0.46 for the mean of hybrids.

Table A9. Grain yields and regression data for the 21 maize pedigree single crosses used in the CW-78 experiment

Hybrid	Grain yields (q/ha)					Regression data[a]			
	N applied (kg N/ha)					Intercept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A x B75	28.5	76.0	103.1	103.8	108.0	30.3	9.10	-25.69	.90
B14A x B76	25.4	70.4	82.8	93.8	90.2	27.8	7.76	-22.43	.85
B14A x B77	39.1	64.4	85.7	94.7	95.9	38.6	5.65	-13.75	.88
B14A x A619	21.7	61.0	91.5	95.8	89.3	21.0	9.03	-26.76	.89
B14A x Va26	21.8	54.4	83.9	98.3	84.7	19.3	8.52	-24.49	.88
B14A x N7A	33.7	59.0	79.6	87.7	92.5	33.6	5.34	-12.18	.89
Mo17 x B75	40.1	68.6	88.7	95.9	106.6	41.0	5.33	-11.01	.78
Mo17 x B76	31.4	67.7	106.5	108.1	109.9	30.1	8.92	-24.10	.92
Mo17 x B77	42.7	69.8	86.8	94.6	95.8	43.0	5.45	-13.88	.82
Mo17 x A619	41.6	79.0	78.3	79.5	86.2	46.5	4.63	-13.51	.66
Mo17 x Va26	43.4	68.9	92.7	93.1	100.2	43.5	5.53	-13.70	.75
Mo17 x N7A	39.7	71.5	90.5	100.8	100.9	40.0	6.38	-16.40	.85
B73 x B75	38.7	81.1	119.6	104.3	106.1	39.1	9.69	-30.64	.84
B73 x B76	37.8	74.5	91.8	99.5	99.0	39.0	6.92	-19.14	.89
B73 x B77	49.0	78.5	102.2	98.5	104.7	49.7	6.11	-16.77	.82
B73 x A619	34.5	72.9	92.6	90.8	103.6	37.3	6.48	-16.50	.80
B73 x Va26	33.3	66.3	86.1	90.0	79.3	33.1	7.33	-23.47	.86
B73 x N7a	47.5	81.9	99.2	103.3	109.3	49.3	6.16	-15.93	.92
B14A x Mo17	21.5	79.3	96.4	93.9	100.2	26.4	9.32	-27.86	.80
B14A x B73	29.6	55.5	70.1	76.7	80.6	30.4	4.85	-11.84	.64
B73 x Mo17	46.4	80.1	101.4	108.7	113.4	47.2	6.56	-16.31	.87
Mean	35.6	70.5	91.9	95.8	97.9	36.5	6.91	-18.87	.75

[a]Values for b_ℓ were multiplied by 10^1. The standard error for these linear coefficients by hybrid is 0.85 and 0.19 for the mean of hybrids. Values for b_q were multiplied by 10^4. The standard error for these quadratic coefficients by hybrid is 3.63 and 0.79 for the mean of hybrids.

Table A10. Nitrogen percentages in the grain and regression data for the 21 maize pedigree single crosses used in the CW-78 experiment

Hybrid	Nitrogen percentage					Regression data[a]			
	N applied (kg N/ha)								
	0	56	112	168	224	Intercept	b_ℓ	b_q	R^2
B14A x B75	1.02	1.08	1.36	1.58	1.60	0.97	3.62	-2.89	.86
B14A x B76	1.20	1.19	1.40	1.61	1.65	1.16	1.85	2.30	.84
B14A x B77	1.01	1.11	1.41	1.64	1.75	0.98	3.74	-0.80	.90
B14A x A619	1.21	1.16	1.44	1.61	1.70	1.16	1.68	3.82	.83
B14A x Va26	1.17	1.23	1.49	1.70	1.73	1.13	3.36	-2.41	.86
B14A x N7A	1.10	1.18	1.38	1.57	1.63	1.08	2.74	-0.68	.93
Mo17 x B75	1.04	1.18	1.41	1.60	1.64	1.01	4.12	-5.46	.85
Mo17 x B76	1.11	1.03	1.28	1.43	1.46	1.06	1.35	2.86	.80
Mo17 x B77	0.88	1.05	1.33	1.59	1.63	0.85	5.09	-6.41	.92
Mo17 x A619	0.97	1.02	1.25	1.43	1.45	0.93	2.94	-2.16	.87
Mo17 x Va26	1.01	1.15	1.30	1.53	1.56	1.00	3.37	-3.32	.86
Mo17 x N7A	1.03	1.07	1.31	1.44	1.56	1.00	2.37	0.82	.90
B73 x B75	0.95	1.04	1.23	1.44	1.48	0.92	3.07	-1.93	.92
B73 x B76	1.07	1.03	1.25	1.39	1.46	1.03	1.36	2.89	.83
B73 x B77	0.91	1.01	1.21	1.42	1.49	0.88	3.05	-1.07	.91
B73 x A619	0.96	1.05	1.21	1.39	1.41	0.94	2.78	-2.64	.89
B73 x Va26	1.06	1.15	1.27	1.50	1.57	1.04	2.15	1.32	.90
B73 x N7A	0.92	1.03	1.25	1.35	1.40	0.92	3.47	-5.32	.89
B14A x Mo17	1.13	1.22	1.45	1.69	1.73	1.10	3.38	-1.84	.87
B14A x B73	1.13	1.11	1.38	1.67	1.63	1.07	2.95	-0.73	.72
Mo17 x B73	0.91	1.05	1.28	1.45	1.47	0.88	4.34	-7.21	.93
Mean	1.04	1.10	1.33	1.52	1.57	1.00	2.99	-1.47	.75

[a]Values for b_ℓ were multiplied by 10^3. The standard error for these linear coefficients by hybrids is 0.53 and 0.12 for the mean of hybrids. Values for b_q were multiplied by 10^6. The standard error for these quadratic coefficients by hybrid is 2.26 and 0.47 for the mean of hybrids.

Table A11. Grain yields and regression data for the 9 maize inbreds used in the A-78 experiment

Inbred	Grain yields (q/ha)					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A	18.4	25.8	25.5	27.8	22.3	18.6	1.36	-5.26	.21
B73	45.9	58.8	62.7	59.1	59.0	47.0	2.18	-7.61	.39
B75	34.7	38.8	44.9	45.6	48.9	34.6	0.98	-1.59	.43
B76	43.4	46.9	42.6	46.6	49.3	44.4	-0.13	1.52	.10
B77	38.2	56.2	53.9	54.0	52.7	40.4	2.32	-8.21	.30
Mo17	36.8	39.7	37.8	39.0	38.1	37.2	0.26	-1.02	.02
A619	44.8	49.6	48.2	50.9	48.7	45.2	0.67	-2.26	.09
Va26	42.6	36.2	45.9	47.5	45.3	40.3	0.27	0.10	.08
N7A	47.4	51.1	46.5	57.5	51.0	47.3	0.50	-1.12	.07
Mean	39.1	44.8	45.3	47.5	46.1	39.4	0.93	-2.83	.06

[a]Values for b_ℓ were multiplied by 10^1. The standard error for these linear coefficients by inbred is 0.59 and 0.20 for the mean of inbreds. Values for b_q were multiplied by 10^4. The standard error for these quadratic coefficients by inbred is 2.53 and 0.84 for the mean of inbreds.

Table A12. Nitrogen percentages in the grain and regression data for the 9 maize inbreds used in the A-78 experiment

Inbred	Nitrogen percentage					Regression data[a]			
	N applied (kg/ha)					Intercept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A	2.10	2.20	2.27	2.28	2.33	2.10	1.83	-3.87	.73
B73	1.31	1.45	1.52	1.59	1.62	1.31	2.52	-5.18	.81
B75	1.78	1.92	2.01	1.98	2.04	1.79	2.46	-6.37	.59
B76	1.63	1.74	1.78	1.80	1.79	1.63	2.05	-6.03	.74
B77	1.38	1.60	1.81	1.89	1.97	1.38	4.76	-9.55	.94
Mo17	1.68	1.81	1.87	1.91	1.89	1.68	2.47	-6.91	.55
A619	1.33	1.56	1.72	1.71	1.80	1.34	4.21	-10.14	.92
Va26	1.50	1.65	1.70	1.72	1.73	1.51	2.50	-6.84	.67
N7A	1.51	1.72	1.81	1.82	1.87	1.53	3.53	-9.30	.79
Mean	1.58	1.74	1.83	1.86	1.89	1.59	2.92	-7.13	.21

[a]Values for b_ℓ were multiplied by 10^3. The standard error for these linear coefficients by inbreds is 0.50 and 0.17 for the mean of inbreds. Values for b_q were multiplied by 10^6. The standard error for these quadratic coefficients by inbred is 2.12 and 0.71 for the mean of inbreds.

Table A13. Grain yields and regression data for the 9 maize inbreds used in the CW-78 experiment

Inbred	Grain yields (q/ha) N applied (kg/ha)					Regression data[a]			
	0	56	112	168	224	Intercept	b_ℓ	b_q	R^2
B14A	11.6	24.9	31.8	30.3	30.1	12.2	2.57	-8.08	.55
B73	32.3	54.1	66.3	65.7	63.2	32.9	4.44	-13.97	.77
B75	19.6	44.5	48.6	49.6	47.7	21.7	3.98	-12.88	.79
B76	23.3	43.8	49.9	51.3	53.2	24.9	3.34	-9.53	.67
B77	18.1	42.3	48.8	55.0	53.0	19.5	4.15	-11.95	.80
Mo17	28.8	39.3	45.9	46.6	50.6	29.3	1.88	-4.32	.48
A619	29.1	46.1	57.2	52.3	56.6	30.1	3.21	-9.47	.50
Va26	26.1	31.3	41.9	41.2	45.7	25.6	1.52	-2.87	.46
N7A	36.3	43.7	54.2	54.9	58.3	35.9	1.90	-4.10	.57
Mean	25.0	41.1	49.4	49.7	50.9	25.8	3.00	-8.57	.42

[a]Values for b_ℓ were multiplied by 10^1. The standard error for these linear coefficients by inbred is 0.72 and 0.24 for the mean of inbreds. Values for b_q were multiplied by 10^4. The standard error for these quadratic coefficients by inbred is 3.08 and 1.03 for the mean of inbreds.

Table A14. Nitrogen percentages in the grain and regression data for the 9 maize inbreds used in the CW-78 experiment

Inbred	Nitrogen percentage					Regression data[a]			
	N applied (kg/ha)					Inter-cept	b_ℓ	b_q	R^2
	0	56	112	168	224				
B14A	1.73	2.03	2.13	2.19	2.21	1.75	5.05	-13.66	.81
B73	1.09	1.29	1.52	1.59	1.71	1.09	4.32	- 7.03	.87
B75	1.50	1.63	1.94	1.94	1.99	1.48	4.66	-10.50	.81
B76	1.50	1.57	1.72	1.78	1.76	1.48	2.68	- 6.12	.74
B77	1.37	1.47	1.70	1.85	1.95	1.35	3.14	- 1.91	.87
Mo17	1.24	1.62	1.77	1.91	1.85	1.25	7.26	-20.42	.87
A619	1.14	1.27	1.54	1.67	1.74	1.11	4.24	- 6.21	.86
Va26	1.43	1.60	1.76	1.81	1.78	1.42	4.29	-11.87	.87
N7A	1.27	1.48	1.63	1.77	1.77	1.27	4.40	- 9.37	.87
Mean	1.36	1.55	1.75	1.83	1.86	1.35	4.45	- 9.68	.48

[a]Values for b_ℓ were multiplied by 10^3. The standard error for these linear coefficients by inbred is 0.67 and 0.22 for the mean of inbreds. Values for b_q were multiplied by 10^6. The standard error for these quadratic coefficients by inbred is 2.86 and 0.95 for the mean of inbreds.

Table A15. Initial grain yields and maximum grain yields for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	Initial grain yields (q/ha)												
B75	74.6	72.3	30.3	81.7	69.3	41.0	95.8	87.1	39.1	84.0	76.2	36.8	65.7
B76	73.5	77.6	27.8	84.8	82.7	30.1	82.3	78.7	39.0	80.2	79.7	32.3	64.1
B77	77.8	79.0	38.6	78.0	72.1	43.0	87.4	80.0	49.7	81.1	77.0	43.8	67.3
A619	67.1	66.7	21.0	70.9	70.8	46.5	90.0	75.9	37.3	76.0	71.1	34.9	60.7
Va26	51.0	57.1	19.3	75.6[a]	71.4[a]	43.5	97.1	64.7[a]	33.1	74.6	64.4	32.0	57.0
N7A	70.4	68.6	33.6	82.3	80.6	40.0	87.6	84.3	49.3	80.1	77.8	41.0	66.3
Mean	69.1	70.2	28.4	78.9	74.5	40.7	90.0	78.5	41.3	79.3	74.4	36.8	63.5
	Maximum grain yields (q/ha)												
B75	110.8	115.2	110.9	105.6	99.9	105.5	126.3	116.8	115.7	114.2	110.6	110.7	111.9
B76	105.4	101.9	94.9	111.0	101.6	112.7	111.3	104.4	101.6	109.2	102.6	103.1	105.0
B77	112.3	106.3	96.6	110.7	106.3	96.5	128.7	114.3	105.3	117.2	109.0	99.5	108.6
A619	95.1	104.9	97.3	86.3	89.4	86.2	106.3	107.4	101.0	95.9	100.6	94.8	97.1
Va26	91.3	107.3	93.4	116.3[a]	102.2[a]	99.3	116.6	101.4[a]	90.3	108.1	103.6	94.3	102.0
N7A	101.6	96.5	92.1	107.4	102.8	102.2	113.9	100.5	108.7	107.6	99.9	101.0	102.9
Mean	102.8	105.4	97.5	106.2	100.4	100.4	117.2	107.5	103.8	108.7	104.4	100.6	104.6

[a]These values were predicted by the graphical method.

Table A16. Rates of N required to maximize yields for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	kgN/ha			kgN/ha			kgN/ha			kgN/ha			
B75	204	166	177	256	157	242	166	170	158	209	164	192	188
B76	147	192	173	136	161	185	155	158	181	146	170	180	165
B77	163	182	205	153	186	196	155	167	182	157	178	194	177
A619	143	184	169	215	185	171	135	202	196	164	190	179	178
Va26	158	199	174	224[a]	224[a]	202	157	168[a]	156	180	197	177	185
N7A	150	233	219	177	172	195	182	163	193	170	189	202	187
Mean	161	193	186	194	181	199	159	171	178	171	182	187	180

[a]These values were predicted by graphical method.

Table A17. Yield responses and yield response per unit N for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	Yield response (q/ha)												
B75	36.2	42.9	80.6	23.9	30.6	64.5	30.5	29.7	76.6	30.2	34.4	73.9	46.2
B76	31.9	24.3	67.1	26.2	18.9	82.6	29.0	25.7	62.6	29.0	23.0	70.8	40.9
B77	34.5	27.3	58.0	32.7	34.2	53.5	41.3	34.3	55.6	36.2	31.9	55.7	41.3
A619	28.0	38.2	76.3	15.4	18.6	39.7	16.3	31.5	63.7	19.9	29.4	59.9	36.4
Va26	40.3	50.2	74.1	40.7[a]	30.8[a]	55.8	19.5	36.7[a]	57.2	33.5	39.2	62.4	45.0
N7A	31.2	27.9	58.5	25.1	22.2	62.2	26.3	16.2	59.4	27.5	22.1	60.0	36.6
Mean	33.7	35.1	69.1	27.3	25.9	59.7	27.2	29.0	62.5	29.4	30.0	63.8	41.1
	Yield response per unit N (kg/kgN)												
B75	17.7	25.8	45.5	9.3	19.5	26.7	18.4	17.5	48.5	15.2	20.9	40.2	25.4
B76	21.7	12.7	38.8	19.3	11.7	44.6	18.7	16.3	34.6	19.9	13.6	39.3	24.3
B77	21.2	15.0	28.3	21.4	18.4	27.3	26.6	20.5	30.5	23.1	18.0	28.7	23.2
A619	19.6	20.8	45.1	7.2	10.1	23.2	12.1	15.6	32.5	12.9	15.5	33.6	20.7
Va26	25.5	25.2	42.6	18.2[a]	13.8[a]	27.6	12.4	21.8[a]	36.7	18.7	20.3	35.6	24.9
N7A	20.8	12.0	26.7	14.2	12.9	31.9	14.3	9.9	30.8	16.4	11.6	29.8	19.3
Mean	21.1	18.6	37.8	14.9	14.4	30.2	17.1	16.9	35.6	17.7	16.6	34.6	23.0

[a]These values were computed from values predicted by graphical method.

Table A18. Gross grain yields per unit N for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	kg/kgN			kg/kgN			kg/kgN			kg/kgN			
B75	54.3	69.4	62.7	41.3	63.6	43.6	76.1	68.7	73.2	57.2	67.2	59.8	61.4
B76	71.7	53.1	54.9	81.6	63.1	60.9	71.8	66.1	56.1	75.0	60.8	57.3	64.4
B77	68.9	58.4	47.1	72.4	57.2	49.2	83.0	68.4	57.9	74.8	61.3	51.4	62.5
A619	66.5	57.0	57.6	40.1	48.3	50.4	78.7	53.2	51.5	61.8	52.8	53.2	55.9
Va26	57.8	53.9	53.7	51.9[a]	45.6[a]	49.2	74.3	60.4[a]	57.9	61.3	53.3	53.6	56.1
N7A	67.7	41.4	42.1	60.7	59.8	52.4	61.9	61.7	56.3	63.4	54.3	50.3	56.0
Mean	64.5	55.5	53.0	58.0	56.3	51.0	74.3	63.1	58.8	65.6	58.3	54.3	59.4

[a]These values were computed from values predicted by graphical method.

Table A19. Initial N yields and maximum N yields for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	Initial N yields (kgN/ha)												
B75	75.8	71.5	24.8	81.5	73.8	35.0	83.4	81.7	30.4	79.5	75.7	30.1	61.8
B76	69.6	78.0	27.2	76.7	79.0	27.0	69.5	67.8	33.9	71.9	74.9	29.4	58.8
B77	74.3	75.4	32.0	68.5	66.4	30.9	73.9	73.0	37.0	72.2	71.6	33.3	59.0
A619	69.2	67.6	20.6	66.5	62.2	36.5	79.9	68.0	29.6	71.8	65.9	28.9	55.6
Va26	59.9	62.2	18.4	69.6[a]	69.4[a]	36.8	86.2	64.5[a]	29.1	71.9	65.4	28.1	55.1
N7A	69.0	67.8	30.7	70.9	74.2	33.8	72.5	76.2	37.5	70.8	72.8	34.0	59.2
Mean	69.3	70.4	25.6	72.3	70.8	33.3	77.6	71.9	32.9	73.0	71.0	30.6	58.2
	Maximum N yields (kgN/ha)												
B75	151.2	158.2	142.7	143.6	137.8	150.8	152.2	146.4	132.6	149.0	147.5	142.0	146.2
B76	134.0	135.5	124.1	128.7	120.3	133.6	125.3	117.9	117.9	129.3	124.6	125.2	126.4
B77	157.3	146.6	139.8	143.9	142.7	130.4	148.3	137.1	125.0	149.8	142.1	131.7	141.2
A619	130.7	140.4	127.8	137.6	108.6	100.1	121.9	122.3	118.4	130.1	123.8	115.4	123.1
Va26	122.2	151.9	129.6	140.5[a]	126.9[a]	129.2	134.4	122.5[a]	107.7	132.4	133.8	122.2	129.4
N7A	130.2	126.9	127.9	125.8	127.0	128.8	120.8	120.9	126.0	125.6	124.9	127.6	126.0
Mean	137.6	143.3	132.0	136.7	127.2	128.8	133.8	127.9	121.3	136.0	132.0	127.4	132.1

[a]These values were computed from values predicted by the graphical method.

Table A20. Nitrogen yield increases and percent N recoveries for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	N yield increases (kgN/ha)												
B75	77.4	86.7	117.9	62.1	64.0	115.8	68.8	64.7	102.2	69.5	71.8	112.0	84.4
B76	64.4	57.5	96.9	52.0	41.3	106.6	55.8	50.1	84.0	57.4	49.6	95.8	67.6
B77	83.0	71.2	107.8	75.4	76.3	99.5	74.4	64.1	88.0	77.6	70.5	98.5	82.2
A619	61.5	72.8	107.2	71.1	46.4	63.6	42.0	54.3	88.8	58.2	57.8	86.5	67.5
Va26	62.3	89.7	111.2	70.9[a]	57.5[a]	92.4	48.2	58.0[a]	78.6	60.5	68.4	94.1	74.3
N7A	61.2	59.1	97.2	54.9	52.8	95.0	48.3	44.7	88.5	54.8	52.2	93.6	66.8
Mean	68.3	72.8	106.4	64.4	56.4	95.5	56.3	56.0	88.3	63.0	61.7	96.7	73.8
	Percent N recovery (kgN/ha)												
B75	38.0	52.2	66.6	24.3	40.8	47.9	41.5	38.1	64.7	34.6	43.7	59.7	46.0
B76	43.8	29.9	56.0	38.3	25.7	57.6	36.0	31.7	46.4	39.4	29.1	53.3	40.6
B77	50.9	39.1	52.6	49.3	41.0	50.8	48.0	38.4	48.4	49.4	39.5	50.6	46.5
A619	43.0	39.5	63.4	33.1	25.1	37.2	31.1	26.9	45.3	35.7	30.5	48.6	38.3
Va26	39.4	45.1	63.9	31.6[a]	25.7[a]	45.8	30.7	34.5[a]	50.4	33.9	35.1	53.3	40.8
N7A	40.8	27.4	44.4	31.0	30.7	48.7	26.2	27.4	45.9	32.7	27.8	46.3	35.6
Mean	42.7	38.5	57.8	34.6	31.5	48.0	35.6	32.8	50.2	37.6	34.3	52.0	41.3

[a]These values were computed from values predicted by the graphical method.

Table A21. Initial relative yields for 18 maize pedigree single crosses used in CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo17			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	%			%			%			%			
B75	67.3	62.8	27.3	77.4	69.4	38.9	75.9	74.6	33.8	73.5	68.9	33.3	58.6
B76	69.7	76.2	29.3	76.4	81.4	26.7	73.9	75.4	38.4	73.4	77.6	31.5	60.8
B77	69.3	74.3	40.0	70.5	67.8	44.6	67.9	70.0	47.2	69.2	70.7	43.9	61.2
A619	70.6	63.6	21.6	82.2	79.2	53.9	84.7	70.7	36.9	79.1	71.1	37.5	62.6
Va26	55.9	53.2	20.7	65.0[a]	69.9[a]	43.8	83.3	63.8[a]	36.7	68.0	62.3	33.7	54.7
N7A	69.3	71.1	36.5	76.6	78.4	39.1	76.9	83.9	45.4	74.3	77.8	40.3	64.1
Mean	67.0	66.9	29.2	74.7	74.3	41.2	77.1	73.1	39.7	72.9	71.4	36.7	60.3

[a]These values were computed from values predicted by the graphical method.

Table A22. Initial N percentages and critical N percentages in the grain of 18 maize pedigree single crosses used in CW-77, A-78, and CW-78 experiments

Parental inbred lines	Parental inbred testers									Means of lines			
	B14A			Mo14			B73						
	Site-year			Site-year			Site-year			Site-year			Mean
	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	CW-77	A-78	CW-78	
	Initial N percentages (%)												
B75	1.17	1.17	0.97	1.18	1.26	1.01	1.03	1.11	0.92	1.13	1.18	0.97	1.09
B76	1.12	1.19	1.16	1.07	1.13	1.06	1.00	1.02	1.03	1.06	1.11	1.08	1.09
B77	1.13	1.13	0.98	1.04	1.09	0.85	1.00	1.08	0.88	1.06	1.10	0.90	1.02
A619	1.22	1.20	1.16	1.11	1.04	0.93	1.05	1.06	0.94	1.13	1.10	1.01	1.08
Va26	1.39	1.29	1.13	1.09[a]	1.15[a]	1.00	1.05	1.18[a]	1.04	1.18	1.21	1.06	1.15
N7A	1.06	1.17	1.08	1.02	1.09	1.00	0.98	1.07	0.90	1.05	1.11	0.99	1.05
Mean	1.20	1.19	1.08	1.09	1.13	0.98	1.02	1.09	0.95	1.10	1.14	1.00	1.08
	Critical N percentages (%)												
B75	1.61	1.63	1.52	1.61	1.63	1.69	1.43	1.48	1.36	1.55	1.58	1.52	1.55
B76	1.50	1.57	1.55	1.37	1.40	1.40	1.33	1.34	1.37	1.40	1.44	1.44	1.43
B77	1.66	1.63	1.71	1.54	1.59	1.60	1.36	1.42	1.40	1.52	1.55	1.57	1.55
A619	1.63	1.58	1.56	1.48	1.44	1.37	1.36	1.35	1.39	1.49	1.46	1.44	1.46
Va26	1.58	1.68	1.64	1.43[a]	1.47[a]	1.54	1.36	1.43[a]	1.41	1.46	1.53	1.53	1.50
N7A	1.52	1.56	1.64	1.39	1.46	1.49	1.25	1.42	1.37	1.39	1.48	1.50	1.46
Mean	1.58	1.61	1.60	1.47	1.50	1.52	1.35	1.41	1.38	1.47	1.50	1.50	1.49

[a]These values were predicted by graphical method.

Table A23. Analyses of variance of 5 predicted parameters for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Source of variation	d.f.	Mean squares				
		N rate for maximum yield	Initial yield	Maximum yield	Initial %N[a]	Critical %N[a]
Site-year	2	1251.13	9742.04**	299.27**	8.55**	0.75**
Hybrid	17	893.00	177.33**	160.22**	1.86**	3.62**
Tester (T)	2	2123.57*	901.60**	326.76**	8.93**	21.58**
Lines (L)	5	681.80	139.93*	241.95**	1.62**	2.36**
T x L	10	752.49	51.17	86.04*	0.57*	0.66**
Error	34	575.52	39.24	32.13	0.26	0.19
Total	53					
C.V.%		13.33	9.86	5.42	4.73	2.94

[a]These values were multiplied by 10^2.

*,**Represent statistical significance at the 5 and 1 percent level of probability, respectively.

Table A24. Analyses of variance of 3 computed efficiency parameters for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Source of variation	d.f.	Mean squares		
		Yield response	Yield response per unit of N[a]	Gross yield per unit of N[a]
Site-year	2	6969.51**	18.19**	5.95**
Hybrid	17	139.85*	0.63*	1.61**
Tester (T)	2	342.38**	1.62**	5.19**
Lines (L)	5	150.89*	0.55+	1.32+
T x L	10	93.83	0.48+	1.05+
Error	34	57.47	0.25	0.58
Total	53			
C.V.%		18.46	21.72	12.80

[a]These values were multiplied by 10^2.

+,*,**Represent statistical significance at the 10, 5, and 1 percent level of probability, respectively.

Table A25. Analyses of variance of 4 computed efficiency parameters and 1 predicted parameter for 18 maize pedigree single crosses used in the CW-77, A-78, and CW-78 experiments

Source of variation	d.f.	Mean squares				
		Initial N yield	Maximum N yield	N yield increase	Percent N recovery	Initial relative yield
Site-year	2	10314.12**	345.84*	7098.29**	1594.16**	7557.72**
Hybrids	17	54.31*	309.65**	327.86**	123.57**	119.83**
Tester (T)	2	149.10**	464.80**	1140.28**	353.93**	484.83**
Lines (L)	5	55.80+	790.67**	557.05**	164.18**	100.12*
T x L	10	34.61	38.11	50.78	57.19	56.84
Error	34	25.48	67.60	86.12	33.78	33.74
Total	53					
C.V.%		8.67	6.23	12.57	14.07	9.63

+,*,**Represent statistical significance at the 10, 5, and 1 percent level of probability, respectively.

Table A26. Combined analyses of variance for the observed grain yields and N percentages of the 12 pedigree single crosses used in 2 site-years (A-76 and CW-77)

Source of variation	d.f.	Mean squares	
		Yields	Percent N[a]
Site-years (S)	1	65,945.5812**	78.5540**
Replications (R)	4	1,055.2951**	4.3563
Nitrogen (N)	4	15,713.8580**	347.1810**
Error (a)	40	230.7806	2.6153
Genotypes (G)	11	1,895.8521**	47.6915**
S x G	11	422.5646**	2.5542**
N x G	44	182.8177**	0.8945**
Error (b)	484	91.0670	0.3699
Total	599		
C.V.%		11.26	4.74

[a]These values were multiplied by 10^2.

Table A27. Combined analysis of variance for the observed grain yields of the 21 pedigree single crosses used in 3 site-years (CW-77, A-78, and CW-78)

Source of variation	d.f.	Mean squares
Site-years (S)	2	82,783.6500**
Replications (R)	4	1,888.3877*
Nitrogen (N)	4	69,254.0400**
S x N	8	9,690.7576**
Error (a)	56	737.9912
Genotypes (G)	20	5,151.6905**
S x G	40	646.5800**
N x G	80	223.5684*
S x N x G	160	163.2112*
Error (b)	1200	129.6891
Total	1574	
C.V.%		12.97

Table A28. Combined analysis of variance for the observed N percentages in the grain for the 21 pedigree maize single crosses used in 3 site-years (CW-77, A-78, and CW-78)

Source of variation	d.f.	Mean squares[a]
Site-years (S)	2	69.8914**
Replications (R)	4	7.3402*
S x R	8	10.1235**
Nitrogen (N)	4	1,111.3274**
S x N	8	34.5646**
Error (a)	48	2.4283
Genotypes (G)	20	61.1627**
S x G	40	2.9922**
N x G	80	1.8959**
Error (b)	1360	0.3272
Total	1574	
C.V.%		4.12

[a]These values were multiplied by 10^2.

Table A29. Combined analysis of variance for the observed grain yields of the 9 inbreds used in 2 site-years (A-78 and CW-78)

Source of variation	d.f.	Mean squares
Site-years (S)	1	1,487.0017**
Replications (R)	4	148.7702
Nitrogen (N)	4	3,545.7185**
S x N	4	1,257.0942**
Error (a)	36	80.7900
Genotypes (G)	8	3,961.3769**
S x G	8	279.1546**
N x G	32	107.4602*
Error (b)	352	65.5227
Total	449	
C.V.%		20.67

Table A30. Combined analysis of variance for the observed N percentages in the grain of the 9 inbreds used in 2 site-years (A-78 and CW-78)

Source of variation	d.f.	Mean squares[a]
Site-years (S)	1	132.7606**
Replications (R)	4	4.2397*
Nitrogen (N)	4	252.1229**
S x N	4	17.7598**
Error (a)	36	1.2003
Genotypes (G)	8	191.4033**
S x G	8	5.3135**
N x G	32	2.6230**
S x N x G	32	1.0773**
Error (b)	320	0.4378
Total	449	
C.V.%		3.80

[a]These values were multiplied by 10^2.

Table A31. Nitrogen rates required to maximize grain yields for 12 maize-pedigree single crosses grown in the A-76 and CW-77 experiments

Hybrid	N rate required (kg N/ha)		
	Site-year		Mean
	A-76	CW-77	
A631 x A239	186	152	169
A632 x Oh551	191	148	170
B37 x B70	237	163	200
B70 x B14A	190	205	198
B70 x B73	183	204	194
B75 x A632	195	160	178
B75 x B37	187	171	179
B77 x B37	228	135	182
Oh545 x A632	143	113	128
B14A x B77	185	163	174
Mo17 x N7A	175	177	176
B73 x A619	175	135	155
Mean	190	161	175

Table A32. Nitrogen rates required to maximize grain yields for 21 maize-pedigree single crosses grown in the CW-77, A-78, and CW-78 experiments

Hybrid	N rate required (kg N/ha)			
	Site-year			Mean
	CW-77	A-78	CW-78	
B14A x B75	204	166	177	182
B14A x B76	147	192	173	171
B14A x B77	163	182	205	183
B14A x A619	143	184	169	165
B14A x Va26	158	199	174	177
B14A x N7A	150	233	219	201
Mean	161	193	186	180
Mo17 x B75	256	157	242	218
Mo17 x B76	136	161	185	161
Mo17 x B77	153	186	196	178
Mo17 x A619	215	185	171	190
Mo17 x Va26	224[a]	224[a]	202	217
Mo17 x N7A	177	172	195	181
Mean	194	181	199	191
B73 x B75	166	170	158	165
B73 x B76	155	158	181	165
B73 x B77	155	167	182	168
B73 x A619	135	202	196	178
B73 x Va26	157	168[a]	156	160
B73 x N7A	184	163	193	180
Mean	159	171	178	169
B14A x Mo17	166	224[a]	167	186
B14A x B73	159	224[a]	205	196
Mo17 x B73	192	222	201	205
Grand Mean	171	188	188	182

[a]These values were determined by the graphical method.

Table A33. Nitrogen rates required to maximize grain yields for 9 maize parental inbreds grown in the A-78 and CW-78 experiments

Inbred	N-rate required (kg N/ha)		
	Site-year		Mean
	A-78	CW-78	
B14A	129	159	144
B73	143	159	151
B75	196[a]	154	175
B76	196[a]	175	186
B77	141	174	158
Mo17	129	217	173
A619	148	170	159
Va26	168[a]	264	216
N7A	222	232	227
Mean	164	189	176

[a]These values were determined by the graphical method.